

**4<sup>th</sup> Training Course on WMO SDS-WAS products (satellite and ground observation and modeling of atmospheric dust)**  
*Casablanca-Morocco, November 17-20, 2014*

# Ground observations of mineral dust

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&

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# Index

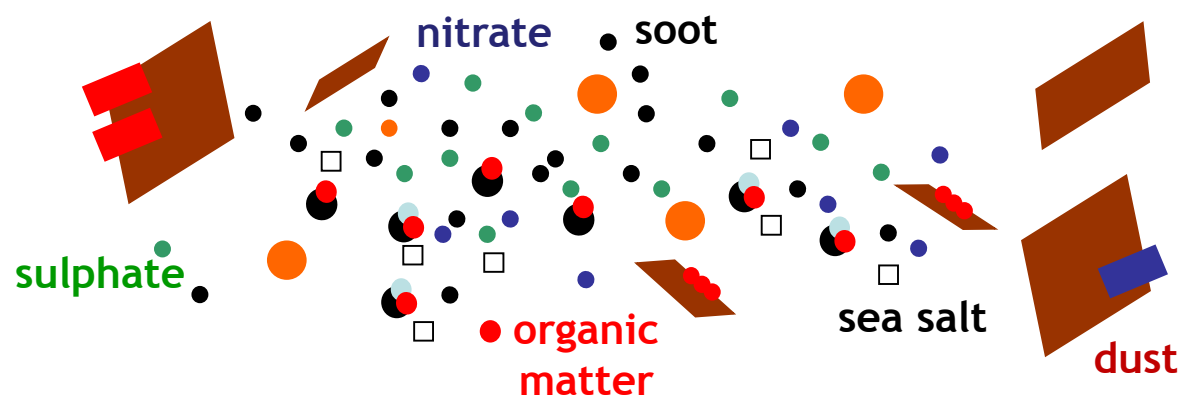
- Aerosols and dust background
- In-situ dust characterization
- In-situ dust estimations (Visibility)
- Ground based remote sensing
- Summary

# Index

- Aerosols and dust background
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**Aerosols:** solid & liquid matter suspended in a gas.

Size 0.001 to 100  $\mu\text{m}$  ( $1 \mu\text{m} = 10^{-6} \text{ m}$ ) = 1 nm ( $10^{-9} \text{ m}$ ) to 100  $\mu\text{m}$  ( $10^{-6} \text{ m}$ ).



## Mineral dust:

Small fragments of soil /crust of the Earth.

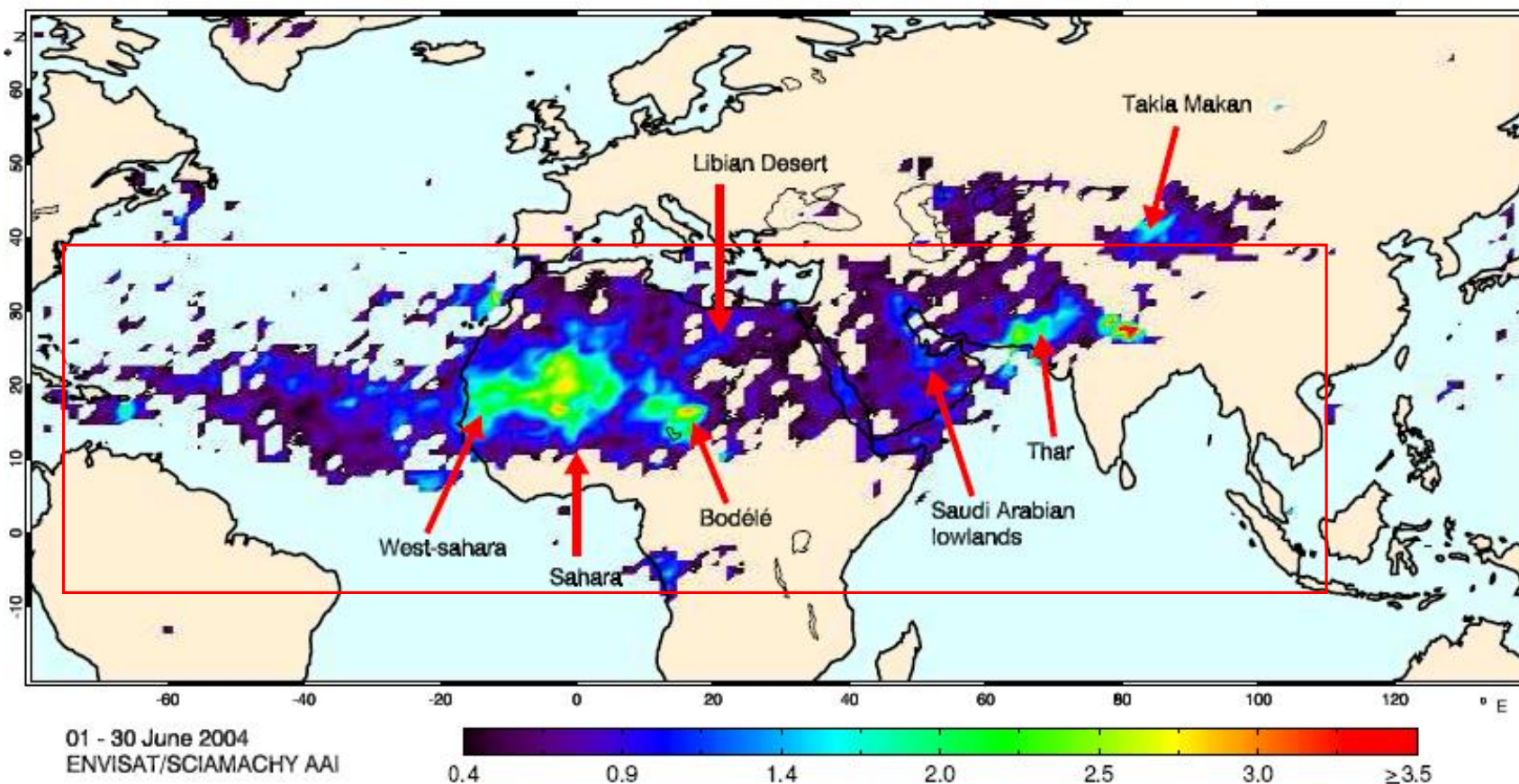
One of the most abundant aerosol in the Earth.



Mineral dust is one of the most important tropospheric aerosols on the global scale

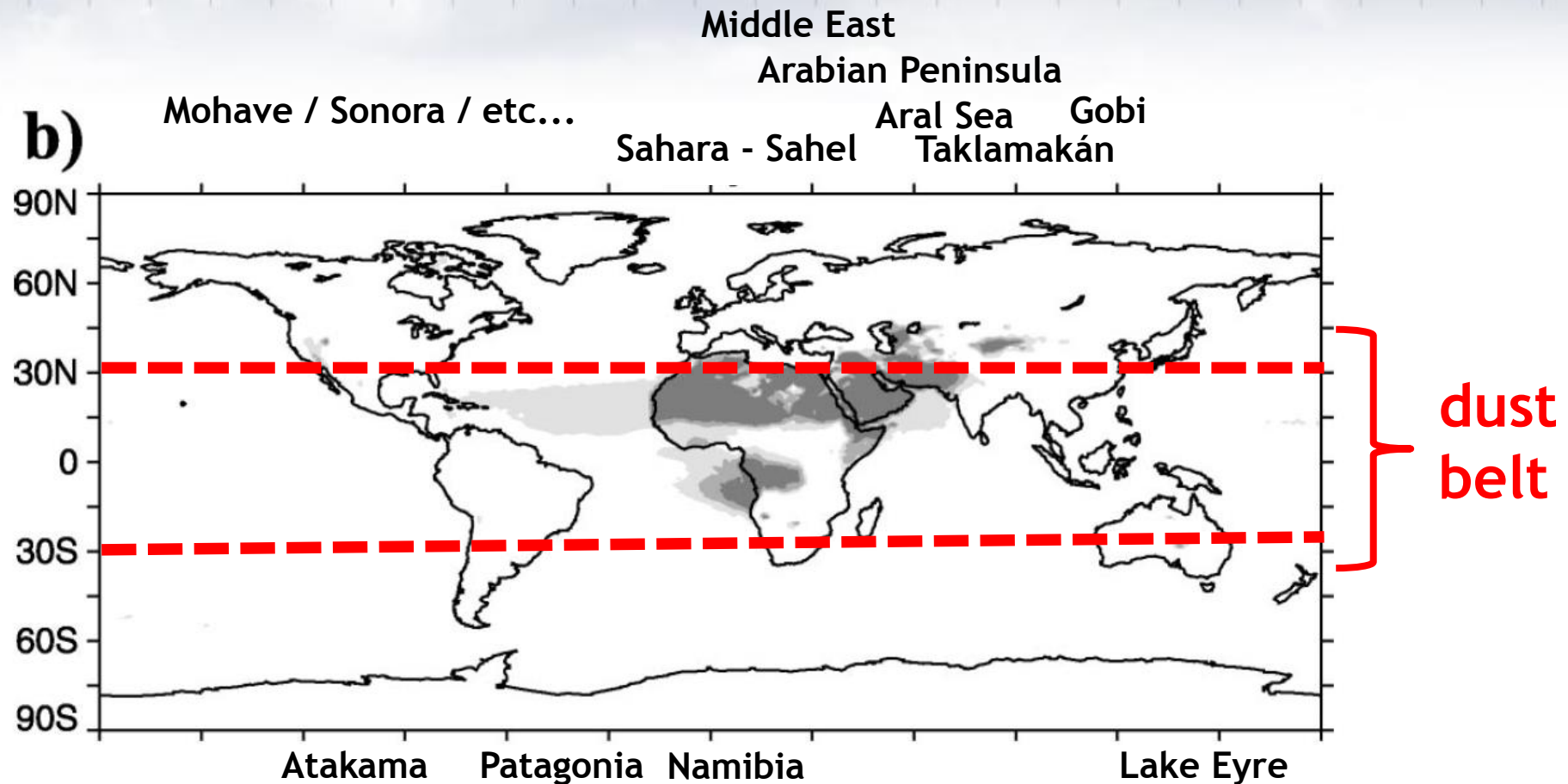
The global distribution is very heterogeneous

The "Global Dust Belt"



Sahara, Sahel, Arabian Peninsula, Thar desert (Middle East), Aral Sea (Central Asia), Taklamakan desert (China), Gobi Desert (China/Mongolia), Lake Eyre Basin (Australia)

(de Graaf, 2006)

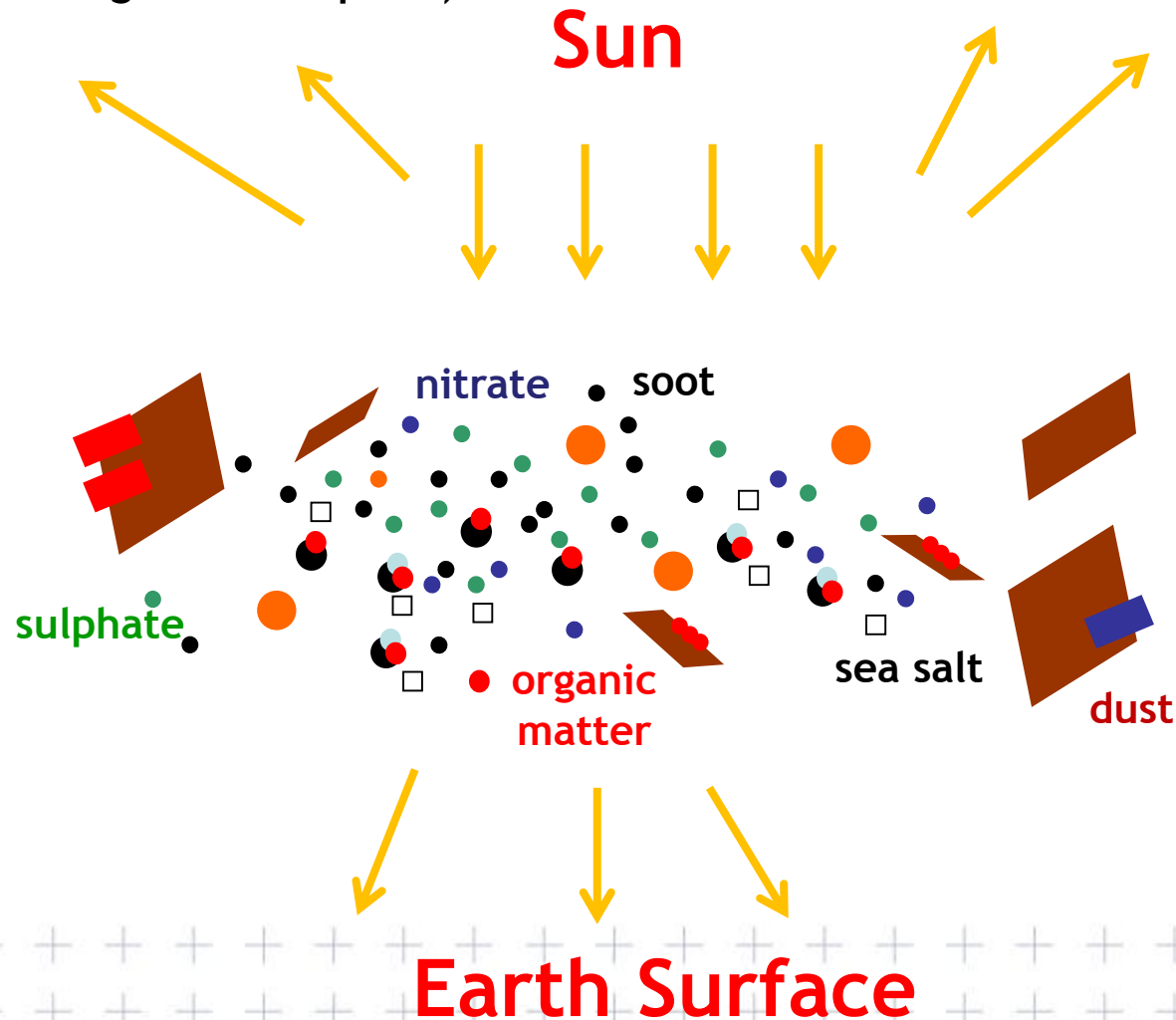


ENVIRONMENTAL CHARACTERIZATION OF GLOBAL  
SOURCES OF ATMOSPHERIC SOIL DUST  
IDENTIFIED WITH THE NIMBUS 7 TOTAL OZONE  
MAPPING SPECTROMETER  
(TOMS) ABSORBING AEROSOL PRODUCT

Joseph M. Prospero,<sup>1</sup> Paul Ginoux,<sup>2</sup> Omar Torres,<sup>3</sup>  
Sharon E. Nicholson,<sup>4</sup> and Thomas E. Gill<sup>5</sup>

## Aerosols & Climate

Direct effects: direct interaction between dust and radiation (scattering and absorption)





## Aerosols & Climate

Direct effects: direct interaction between dust and radiation (scattering and absorption)

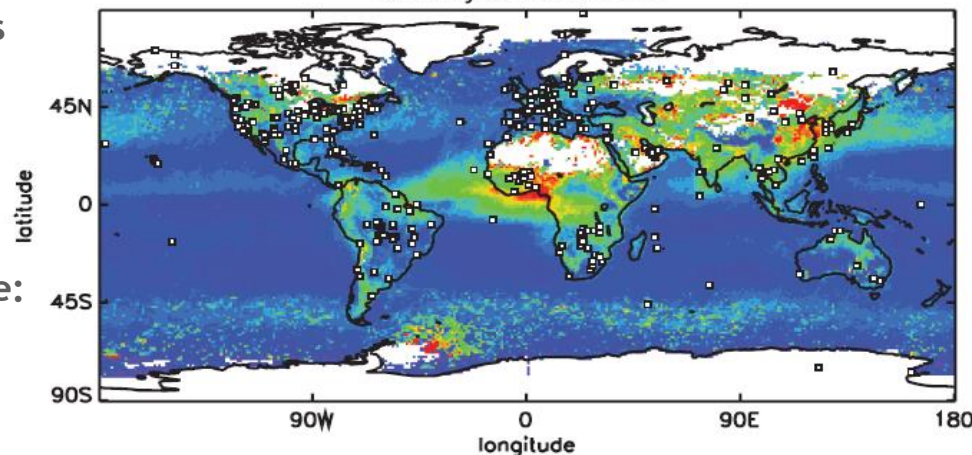
A total direct aerosol radiative forcing combined across all aerosol types can now be given for the first time as  $-0.5 \pm 0.4 \text{ W m}^{-2}$ , with a **medium-low** level of scientific understanding

The direct radiative forcing for individual species remains less certain and is estimated from models to be:

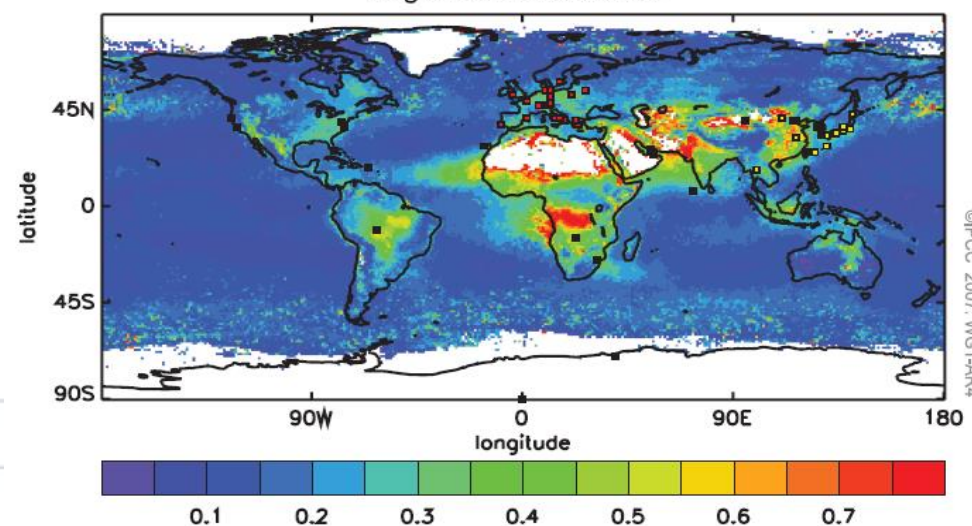
- $-0.4 \pm 0.2 \text{ W m}^{-2}$  sulphate
- $-0.05 \pm 0.05 \text{ W m}^{-2}$  fossil fuel organic carbon
- $+0.2 \pm 0.15 \text{ W m}^{-2}$  fossil fuel black carbon
- $+0.03 \pm 0.12 \text{ W m}^{-2}$  biomass burning
- $-0.1 \pm 0.2 \text{ W m}^{-2}$  for nitrate
- $-0.1 \pm 0.2 \text{ W m}^{-2}$  for mineral dust

### TOTAL AEROSOL OPTICAL DEPTH

January to March 2001

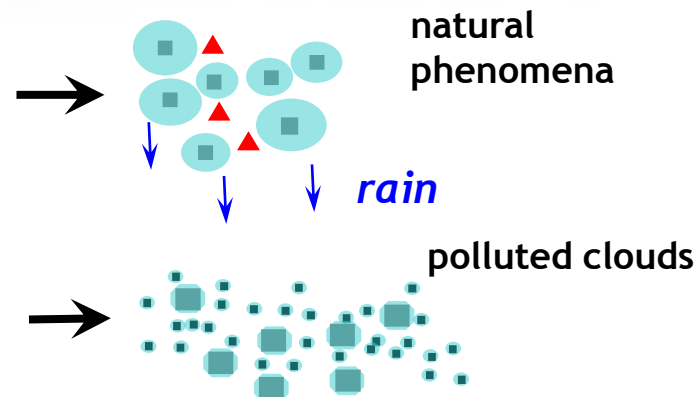
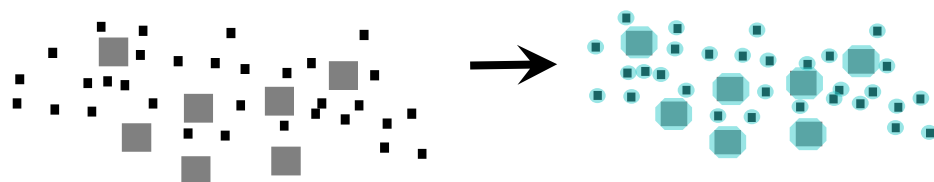


August to October 2001



## Aerosols & Climate

Indirect effects: change in the optical properties of clouds due to interaction with anthropogenic-aerosols

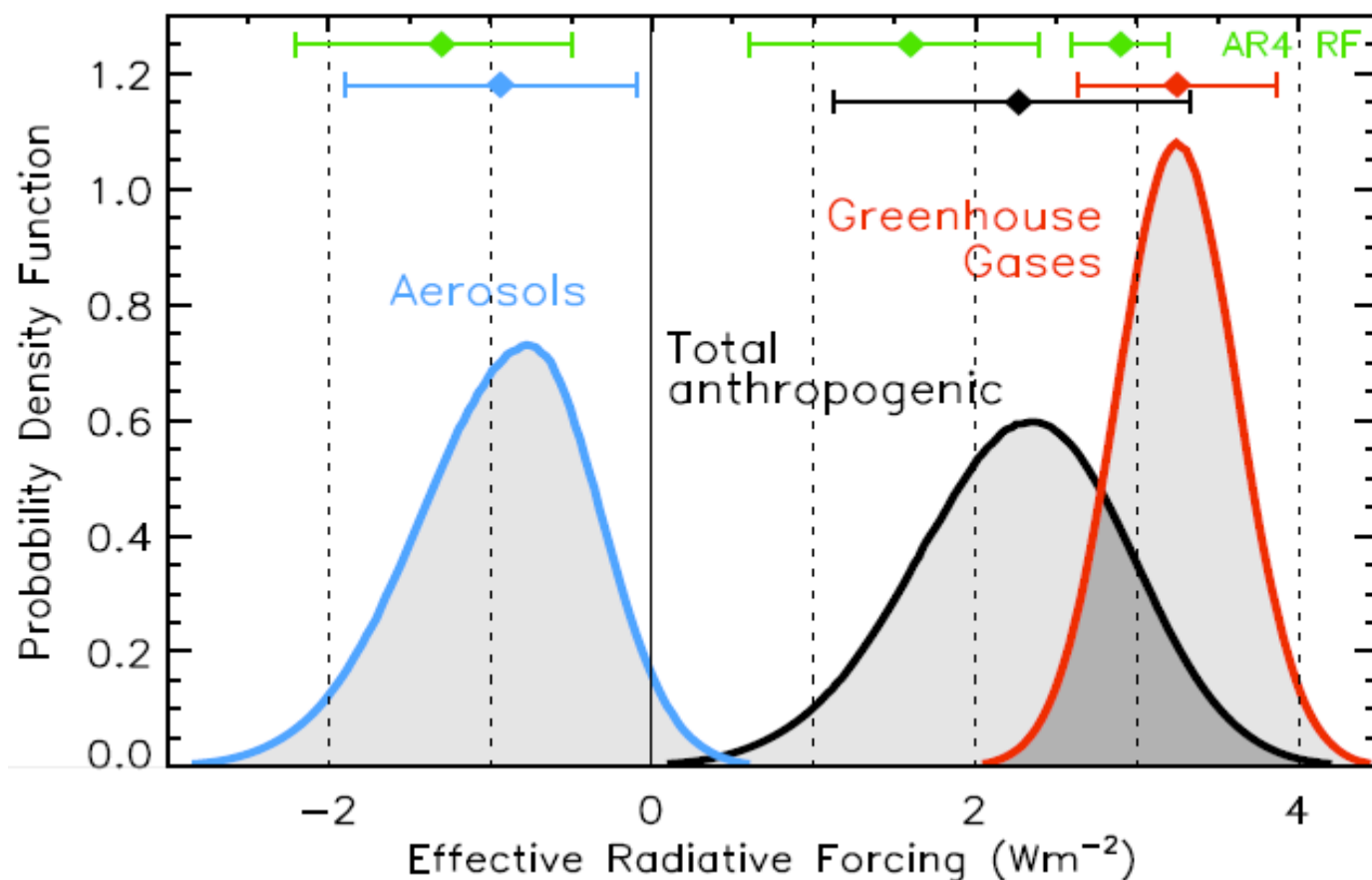


Anthropogenic aerosols effects on water clouds cause an indirect cloud albedo effect (referred to as the first indirect effect in the TAR), which has a best estimate for the first time of  $-0.7$   $[-0.3$  to  $-1.8]$   $\text{W m}^{-2}$ , with a **low level** of scientific understanding

*inhibited rain*  
{ increase in life time of clouds  
change of optical properties  
change of optical properties



Today's uncertainty in the total anthropogenic climate forcing is to a great extent caused by the large aerosol uncertainty





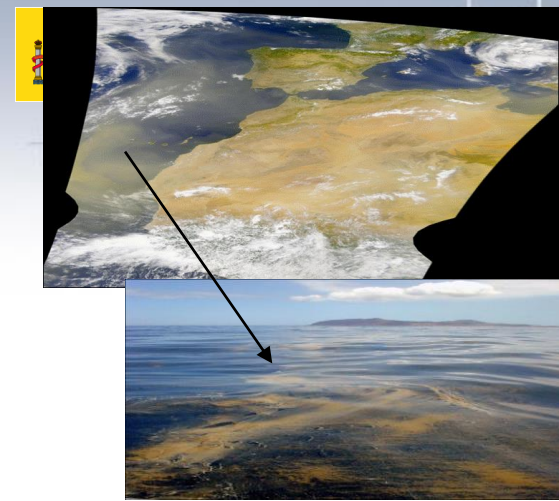
# Background



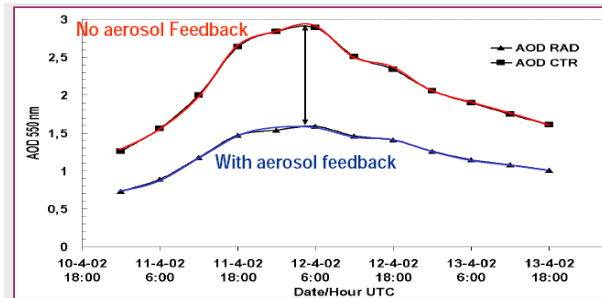
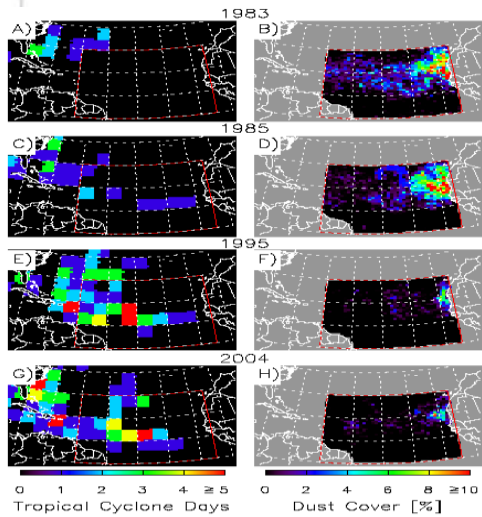
**Human Health** (Asthma, infections, Meningitis in Africa, Valley Fever in the America's)



**Agriculture** (negative & positive impacts)



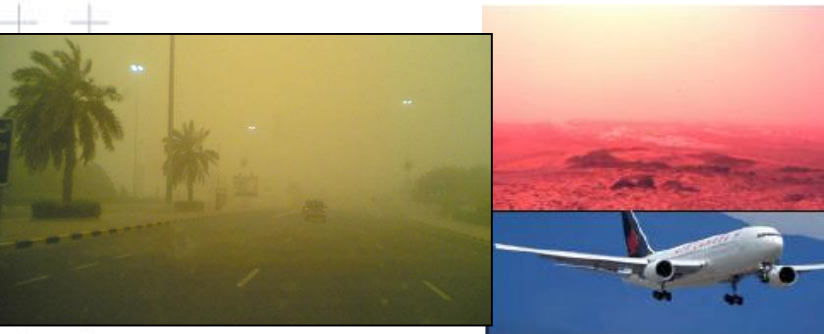
**Marine productivity** (negative & positive impacts)



**Improved Weather and Seasonal Climate prediction**

**Industry** (Semi-conductor, etc.)

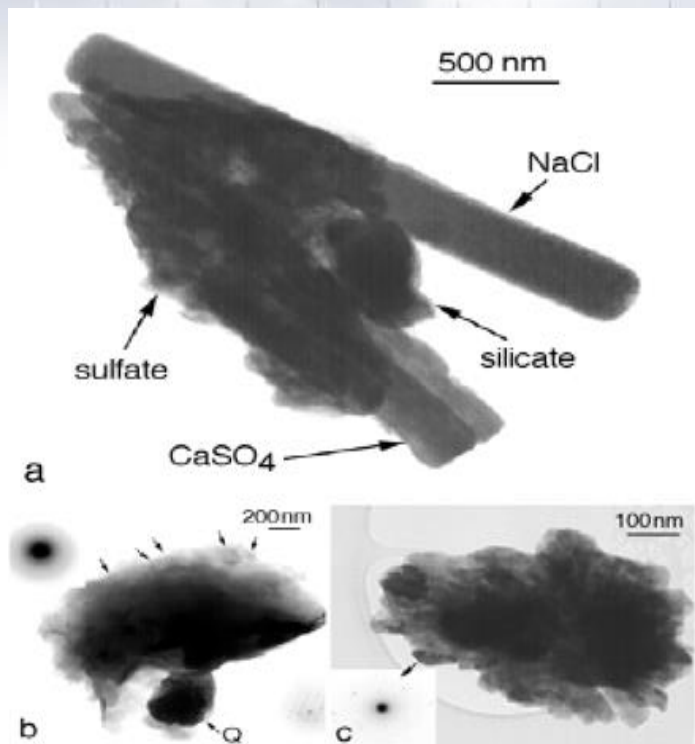
**Energy** (Thermal solar energy)



**Aviation** (air disasters)  
**Ground Transportation**



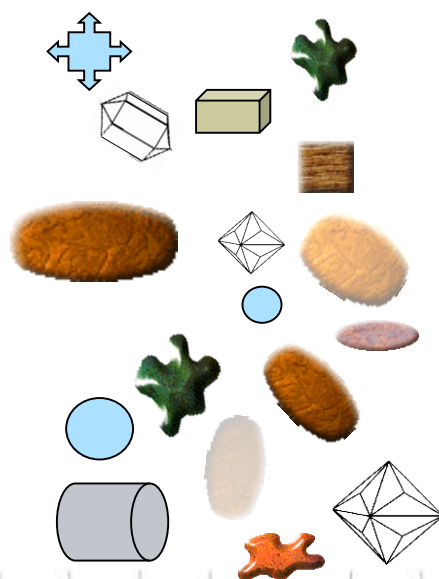




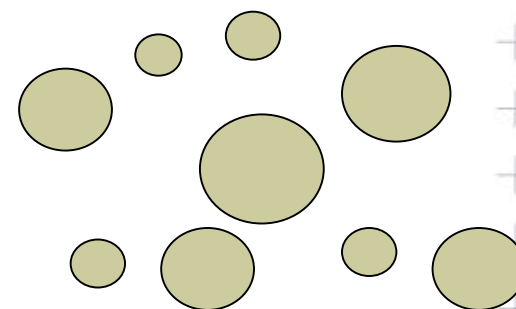
*Busek and Posfai, 1996*

## Dust Particle Images

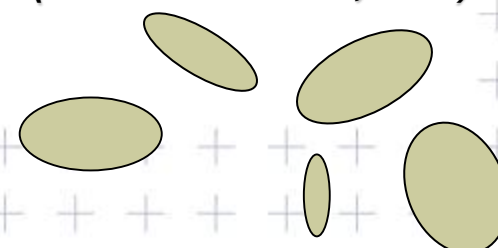
aerodynamic diameter, measured in microns or micrometers ( $\mu\text{m}$ ), a unit equal to one millionth of a meter.



*spherical:*



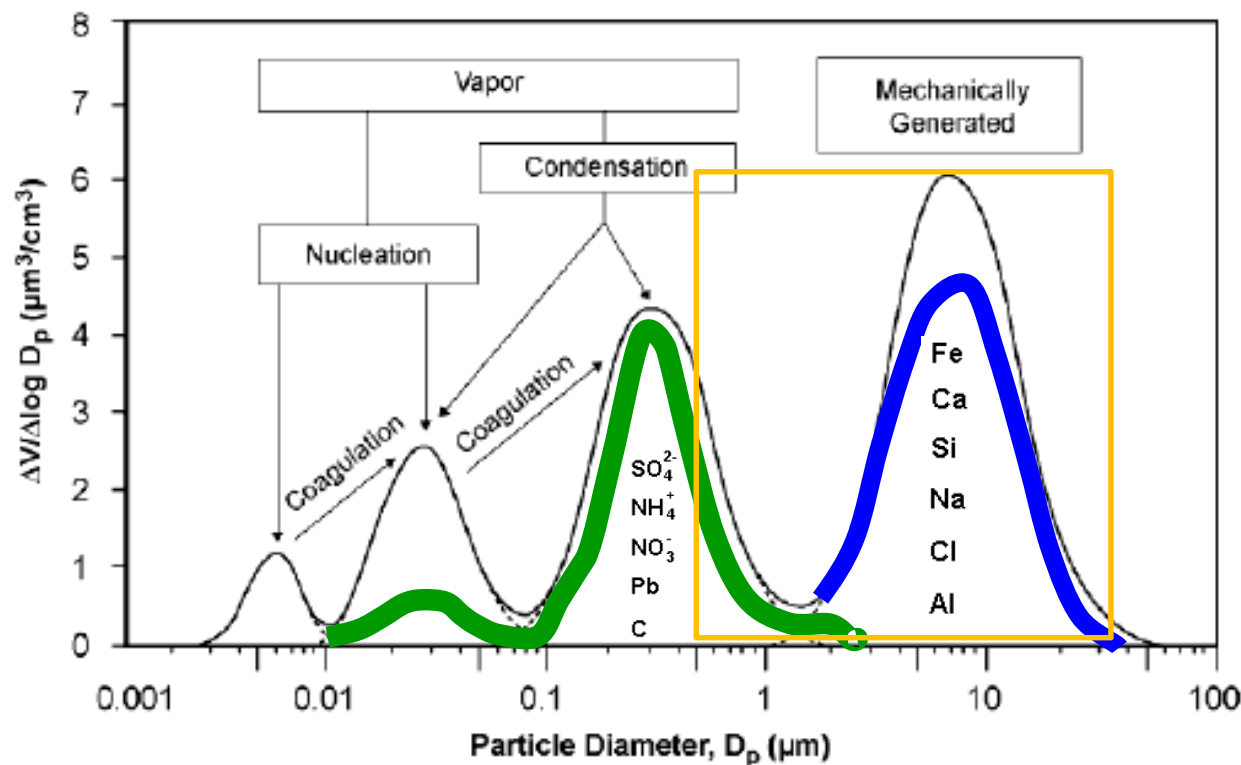
*Randomly oriented spheroids :  
(Mishchenko et al., 1997)*



$PM_{10}$  (diameter <10 microm)

$PM_{2.5}$

$PM_{2.5-10}$



ultrafine  
<0.1  $\mu m$

accumulation  
0.1 - 1  $\mu m$

Coarse  
1 - 10  $\mu m$

Mineral dust :

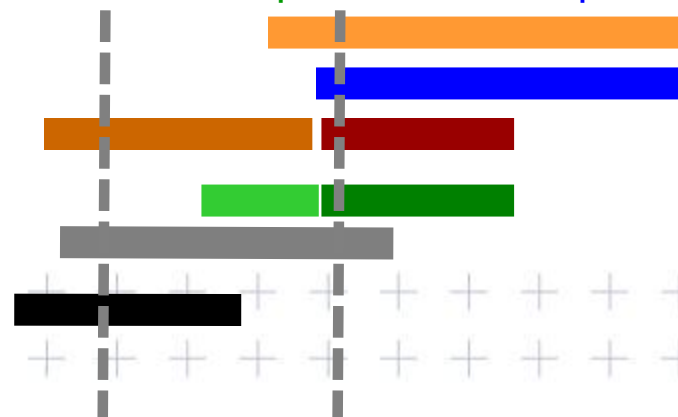
Marine salt:

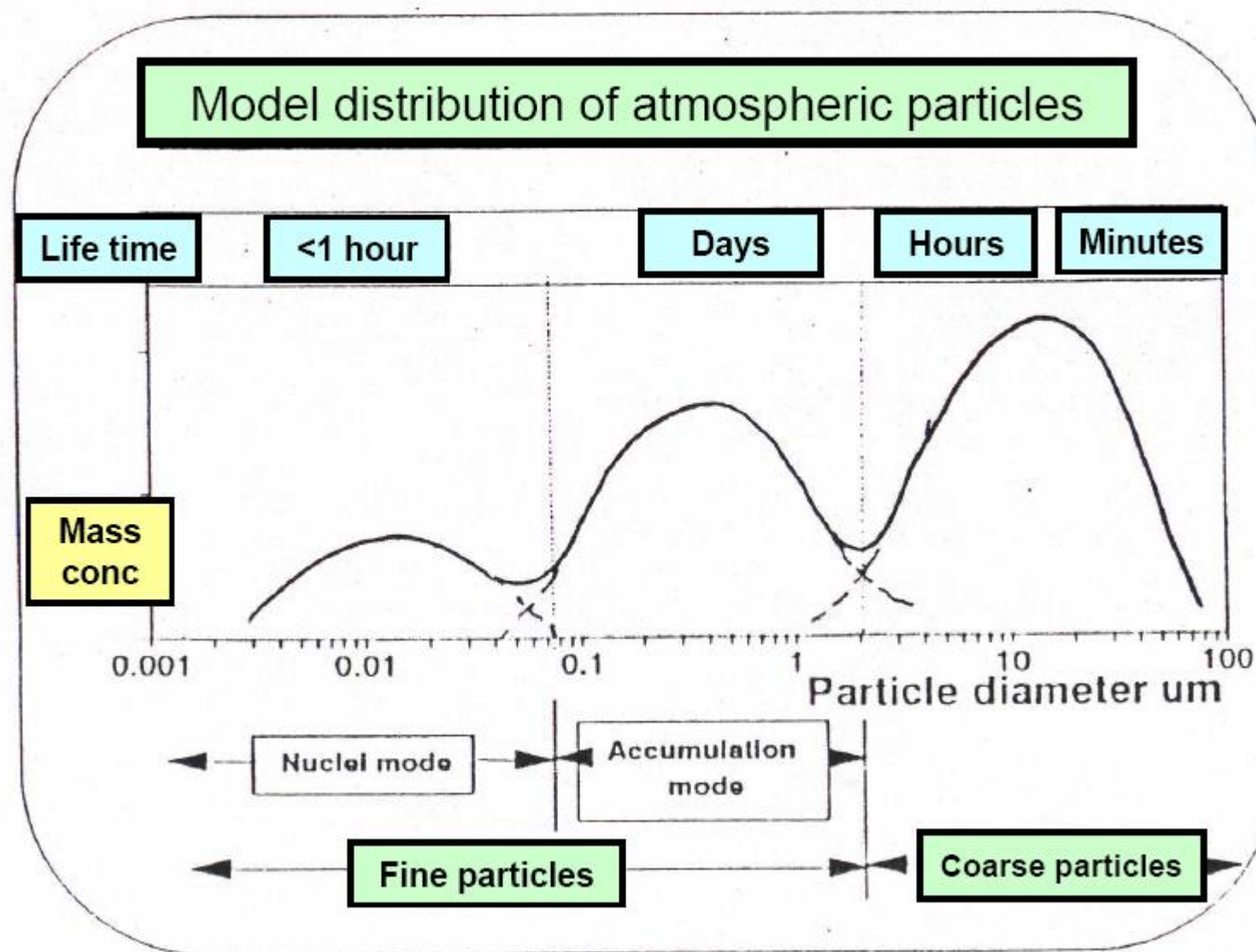
Sulfate:

Nitrate:

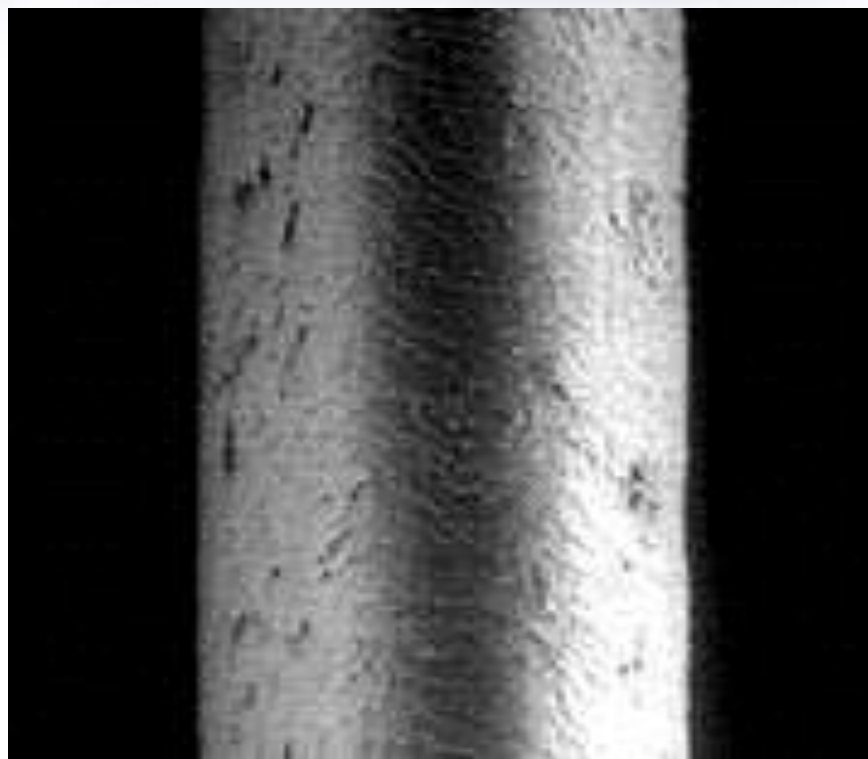
Organic aerosol:

black carbon:

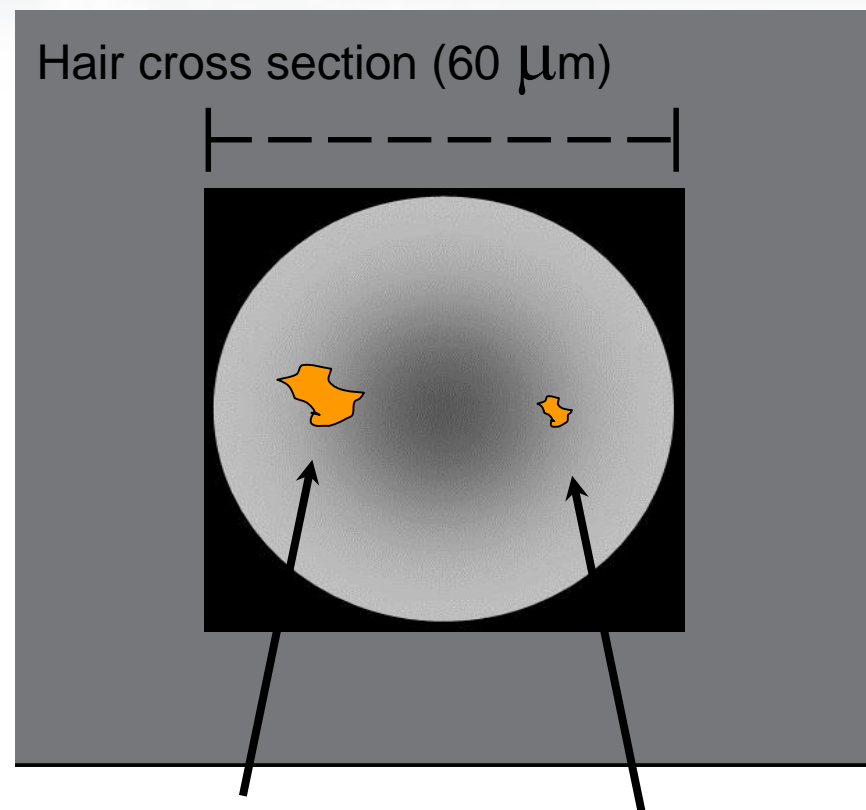




Particles in the Atmosphere: atmospheric residence time Model

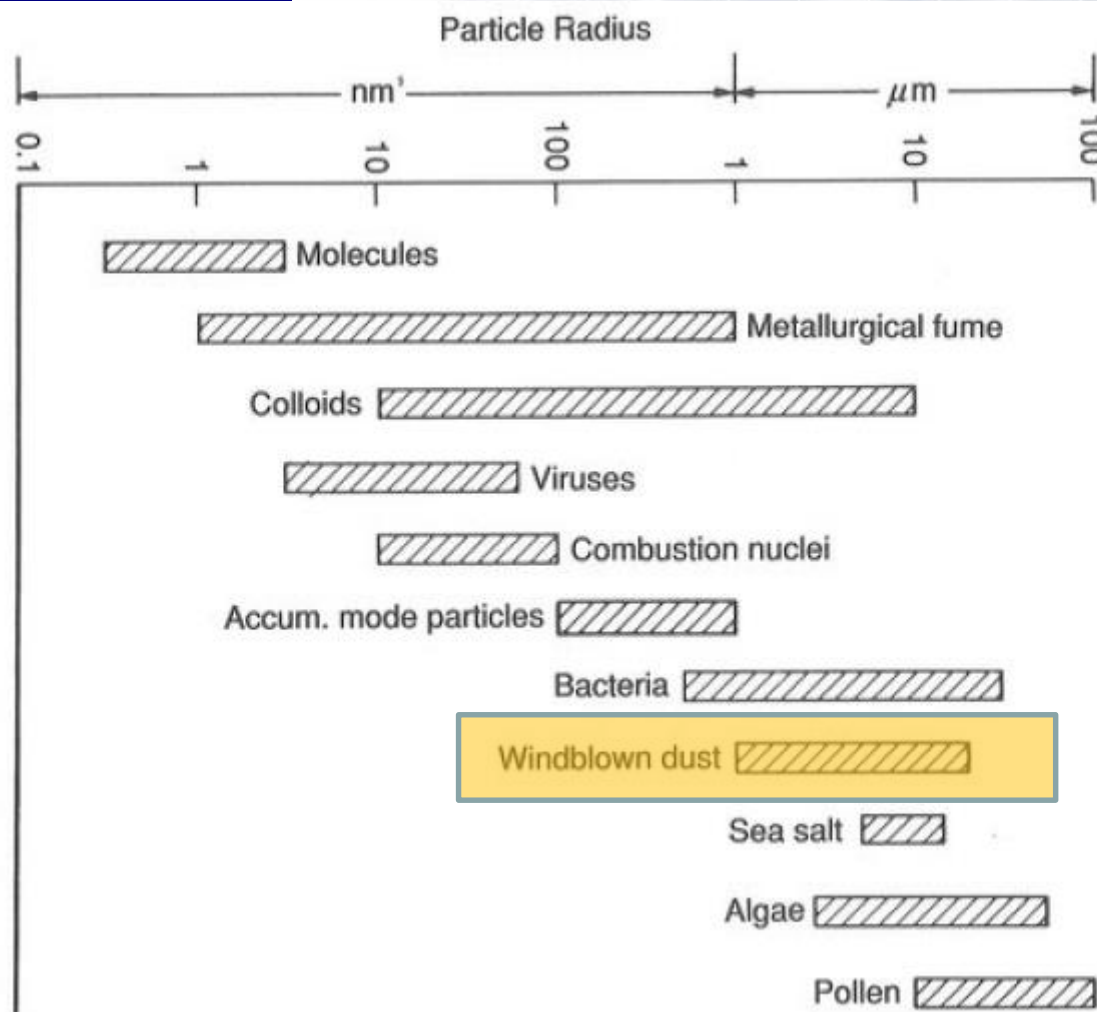


**Human Hair**  
**(60  $\mu\text{m}$  diameter)**



**PM<sub>10</sub>**  
**(10  $\mu\text{m}$ )**

**PM<sub>2.5</sub>**  
**(2.5  $\mu\text{m}$ )**



Size of different atmospheric aerosols, from (Graedel and Crutzen, 1994)

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- Recommended ground-based observations in Middle East
- Summary

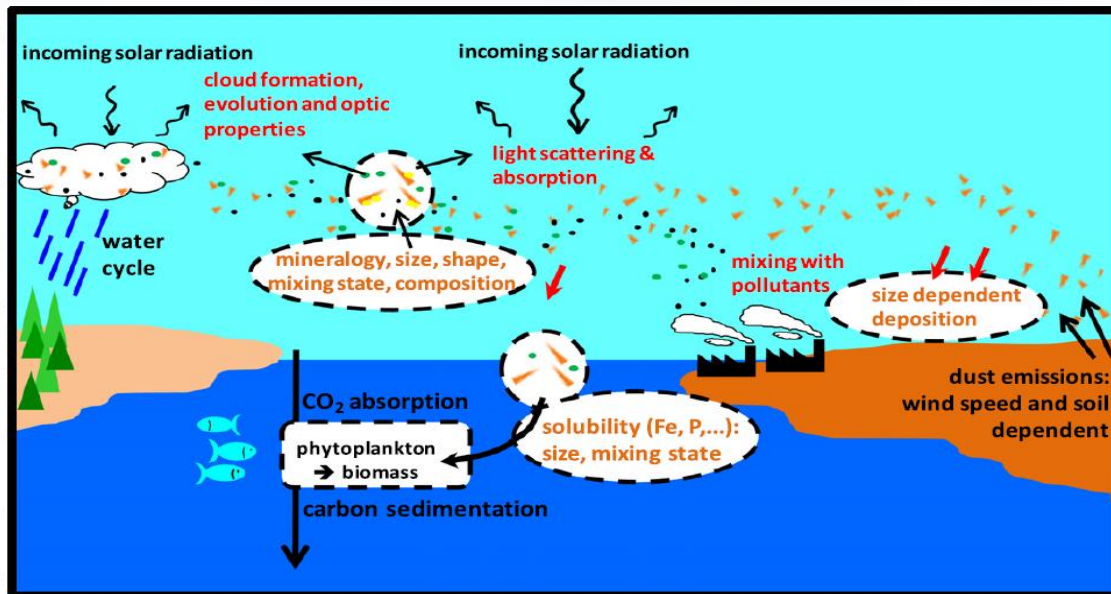


There is a wide variety of aerosol properties that are relevant to climate forcing and human health:

List of recommended parameters by the Aerosol SAG of the Global Atmosphere Watch (GAW) program of WMO

- Multiwavelength optical depth
- Mass in two size fractions
- Major chemical components in two size fractions
- Scattering and hemispheric backscattering coefficient at various wavelengths
- Absorption coefficient
- Aerosol number concentration
- Cloud condensation nuclei (at various supersaturations)
- Aerosol size distribution
- Detailed size fractionated chemical composition
- Dependence on relative humidity
- Vertical distribution of aerosol properties (e.g. LIDAR)

What property of aerosol dust we want to measure ?



number size distribution  
mass concentration  
chemical composition  
mixing state  
mineralogy  
optical properties

  
in-situ techniques

Review Article

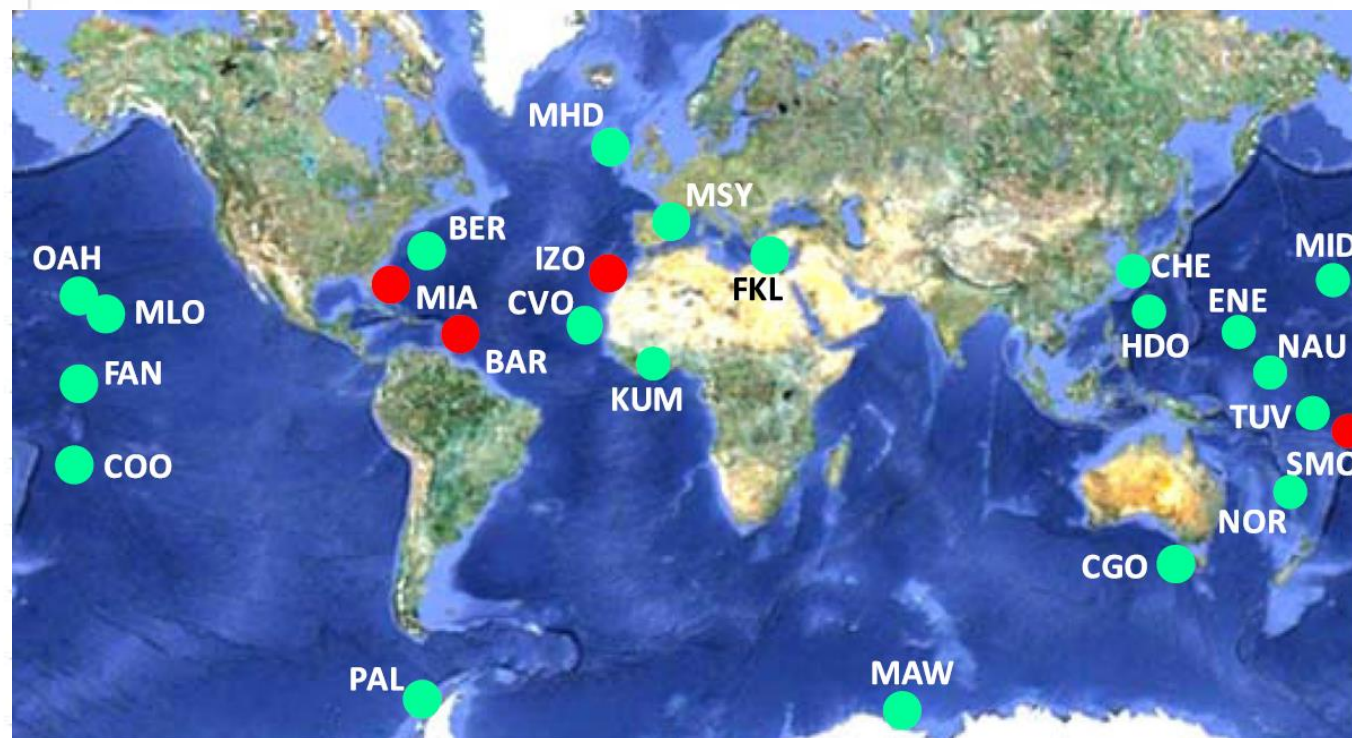
**Aeolian Research** Aeolian Research 6 (2012) 55–74



A review of methods for long term in situ characterization of aerosol dust

Sergio Rodríguez<sup>a,\*</sup>, Andrés Alastuey<sup>b</sup>, Xavier Querol<sup>b</sup>



## Long term monitoring dust background-observatories:



-  at least 4 years
-  Active during the last 20 years

Review Article

**Aeolian Research** Aeolian Research 6 (2012) 55–74

A review of methods for long term in situ characterization of aerosol dust

Sergio Rodríguez<sup>a,\*</sup>, Andrés Alastuey<sup>b</sup>, Xavier Querol<sup>b</sup>

## property of aerosol dust:

**number size distribution**

mass concentration

chemical composition

mixing state

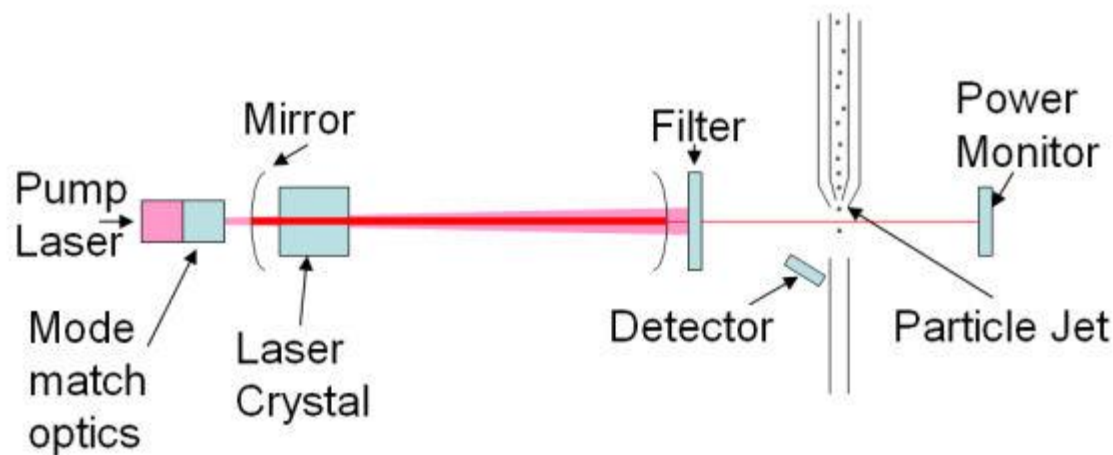
mineralogy

optical properties

## property of aerosol dust: **number size distribution**

### 1. Optical Particle Counter OPC: 0.5 - 20 $\mu\text{m}$

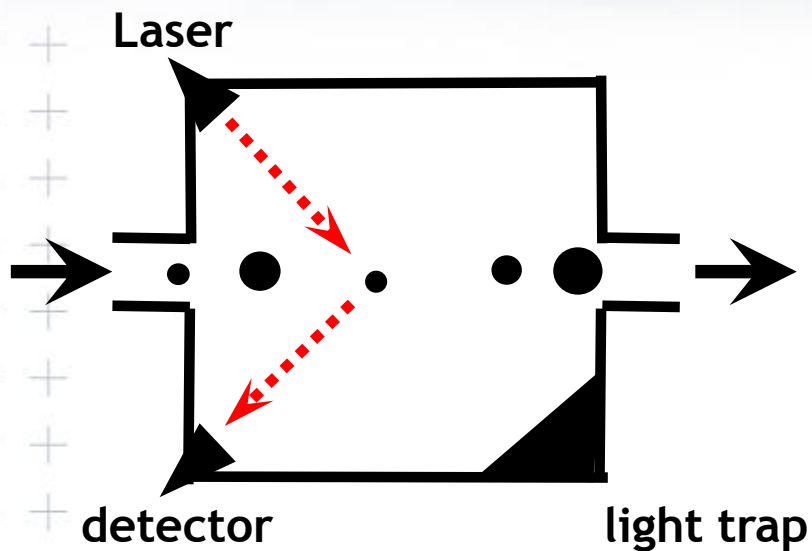
Optical Particle Counters (OPC) use a high-intensity light source (a laser), a controlled air flow (viewing volume), and highly sensitive light gathering detectors (a photodetector).



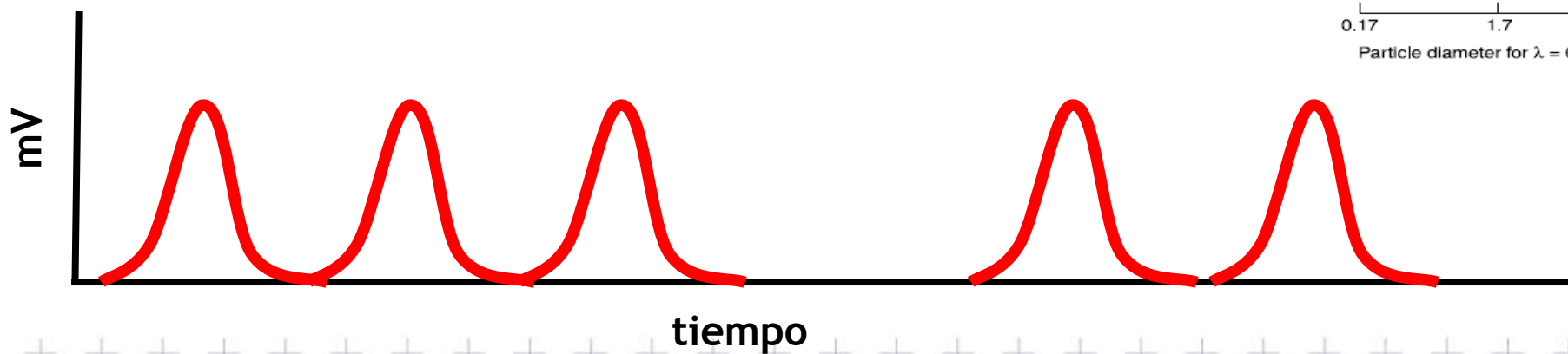
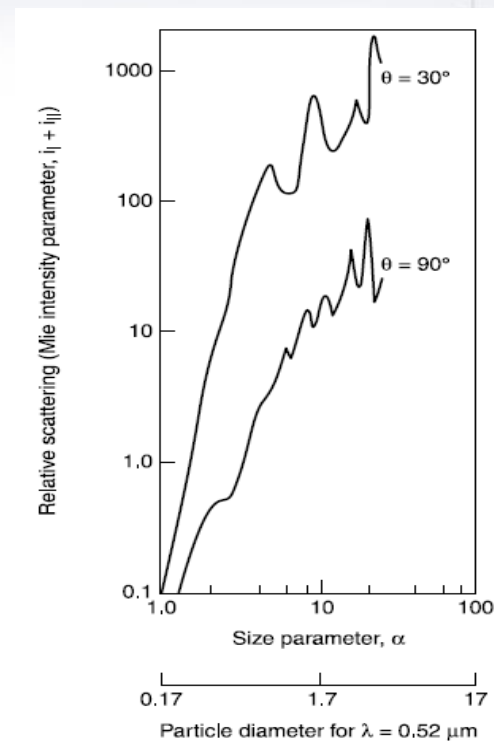
Relationship between pulse height (signal in detector) and the size of the particle depends on unknown particle parameters

Particle counters count pulses of scattered light from particles, or in some cases

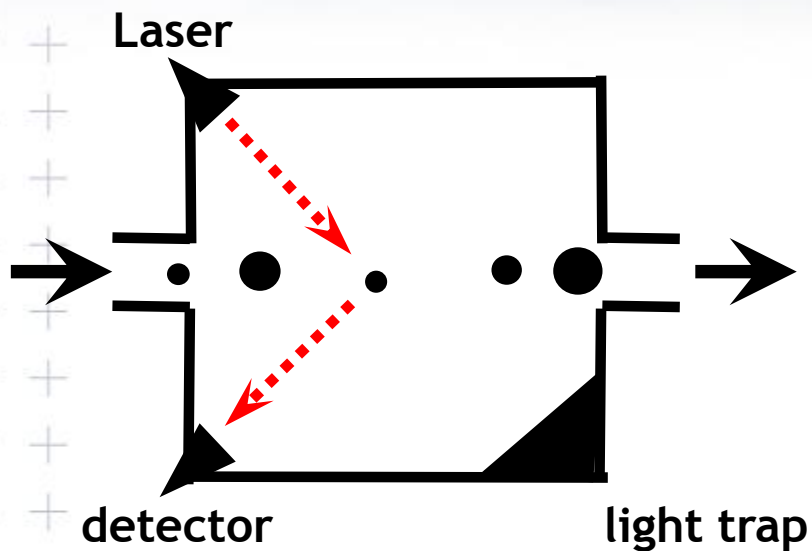
## 1. Optical Particle Counter OPC: 0.5 - 20 $\mu\text{m}$



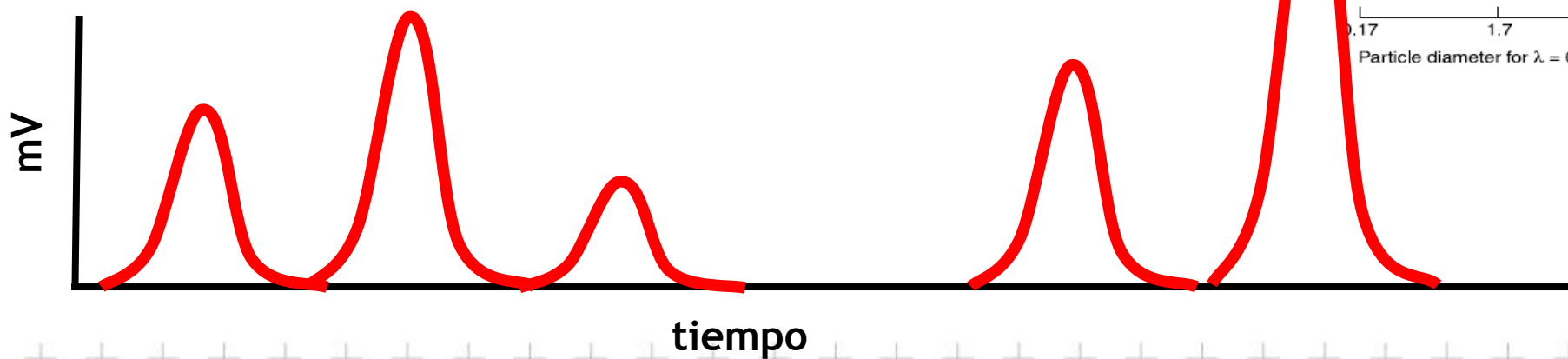
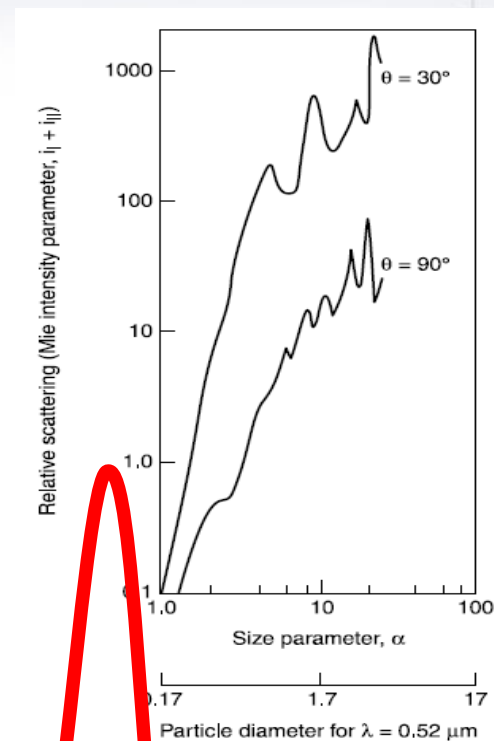
Intensidad del scattering  
 $I(dp, \theta, \lambda, m)$



## 1. Optical Particle Counter OPC: 0.5 - 20 $\mu\text{m}$



Intensidad del scattering  
 $I(dp, \theta, \lambda, m)$





# property of aerosol dust: **number size distribution**

## 1. Optical Particle Counter OPC: 0.5 - 20 $\mu\text{m}$

### Disadvantage / sources of uncertainties:

Relationship between pulse height (signal in detector) and the size of the particle depends on unknown particle parameters:

refractive index and shape



$$m = n + k \cdot i$$

e.g. some commercial instruments

$$m = 1.5 + 0 \cdot i$$

OPC are very useful instruments,  
but sources of uncertainties should  
be known:

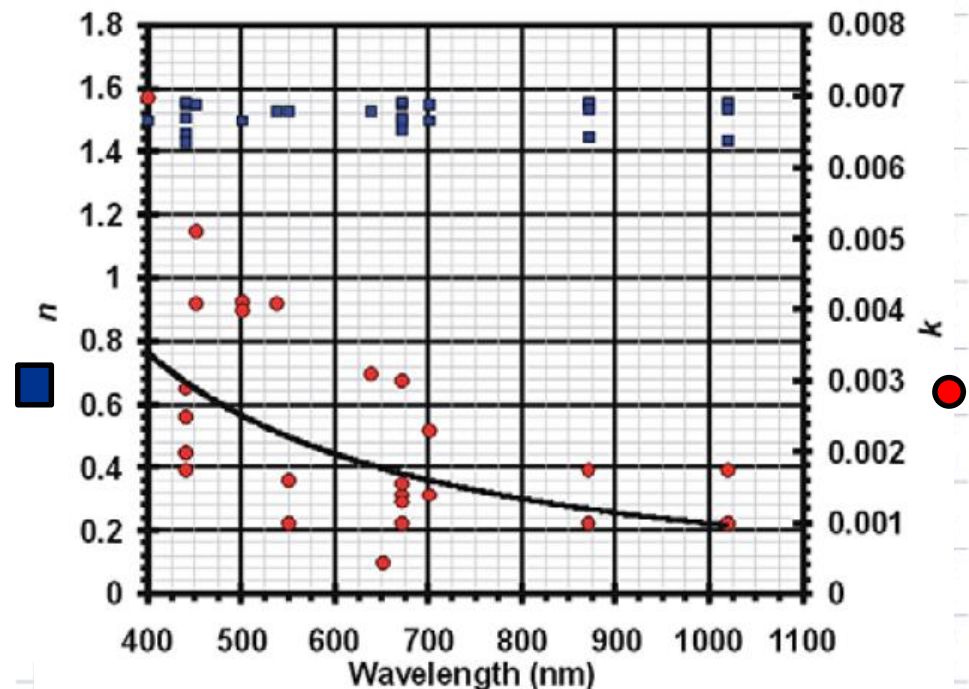
Particle size (?)  $\rightarrow$  diameter of the  
calibration polystyrene spheres (PLS)



Light scattering and absorption by wind blown dust: Theory, measurement, and recent data

Haley E. Redmond, Kathy D. Dial, Jonathan E. Thompson • *Aeolian Research 2 (2010) 5–26*

### refractive index of dust



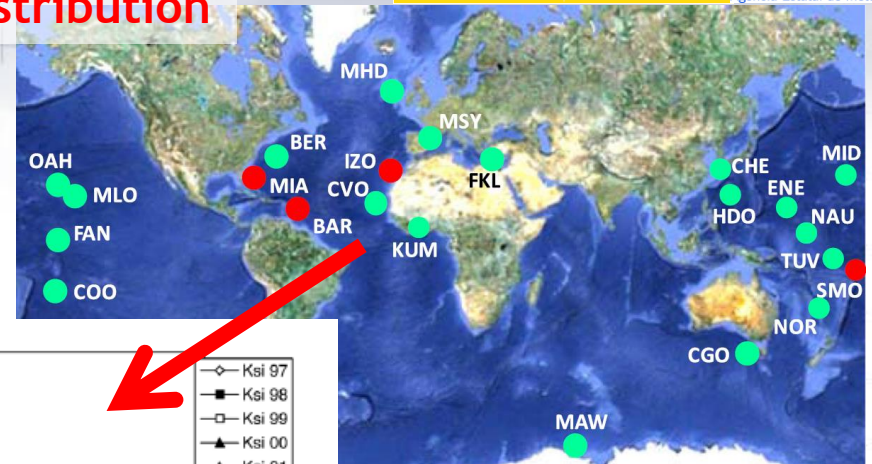
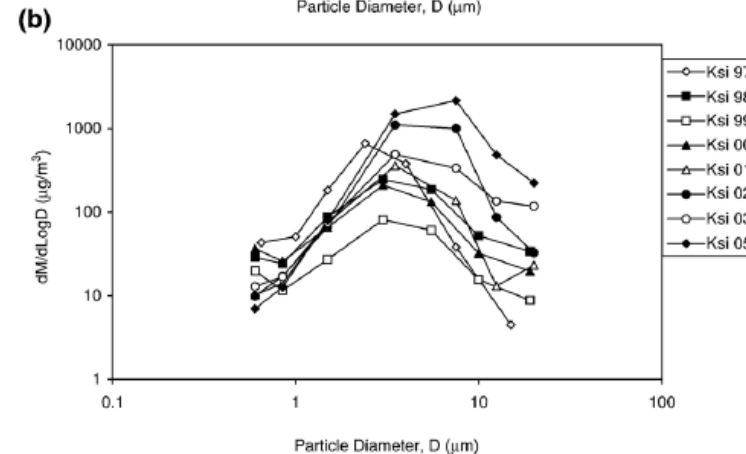
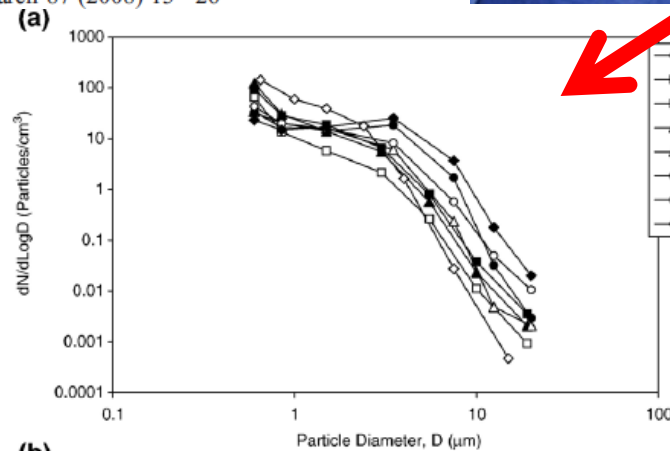
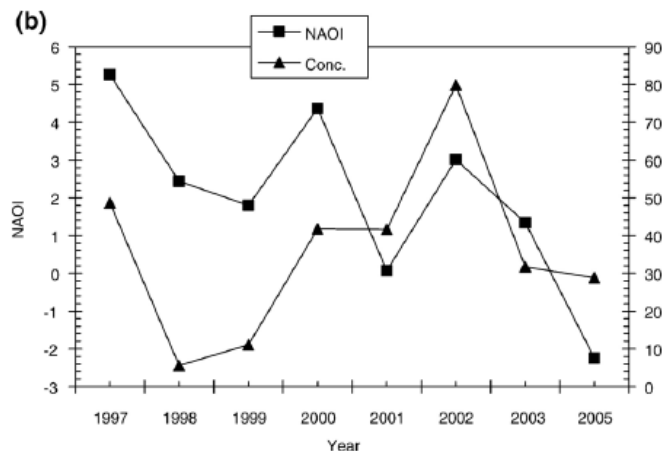
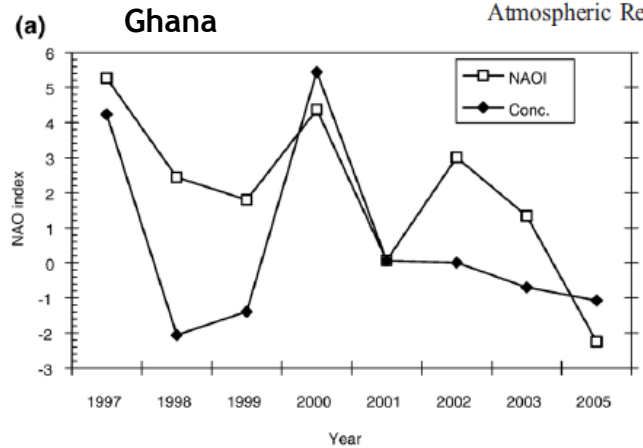
# property of aerosol dust: number size distribution

## 1. Optical Particle Counter OPC: 0.5 - 20 μm

A long-term experimental study of the Saharan dust presence in West Africa

A. Sunnu<sup>a</sup>, G. Afeti<sup>a</sup>, F. Resch<sup>b,\*</sup>

Atmospheric Research 87 (2008) 13–26



review Article  
review of methods for long term in situ characterization of aerosol dust  
rgio Rodríguez<sup>a,\*</sup>, Andrés Alastuey<sup>b</sup>, Xavier Querol<sup>b</sup>

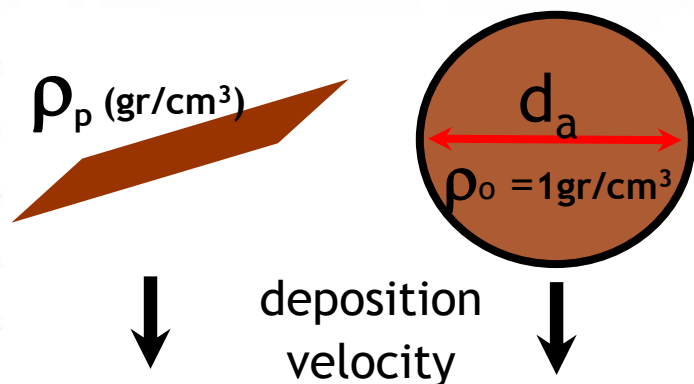
$$\frac{dV}{d \log D} = \frac{\pi}{6} d^3 \frac{dN}{d \log D}$$

Fig. 3. Inter-annual comparison of number and mass frequency distributions at Kumasi (Ksi).

property of aerosol dust: **number size distribution**

1. Optical Particle Counter OPC

2. Aerodynamic Particle Sizer: 0.7 - 20  $\mu\text{m}$



$$da \cong dp \cdot \left( \sqrt{\frac{\rho_p}{\rho_o}} \right) \quad \begin{array}{l} \rho_p = 2.6 \text{ g/cm}^3 \text{ dust} \\ \rho_o = 1 \text{ g/cm}^3 \end{array}$$

1.6

$$da = 1.6 dp$$

$$da > dp$$

The aerodynamic diameter of a particle is the diameter that would have a particle of density 1  $\text{g/cm}^3$  that settle at the same velocity of our dust - particles

$$V_{TS} = \frac{\rho_p \cdot dp^2 \cdot g}{18 \eta} = \frac{\rho_o \cdot da^2 \cdot g}{18 \eta}$$

$dp$  = geometric diameter

$da$  = aerodynamic diameter

$da, \mu\text{m}$	$dp, \mu\text{m}$
20.0	12.5
10.0	6.25
3.0	1.875
1.0	0.625
0.5	0.3125



# property of aerosol dust: **number size distribution**

1. Optical Particle Counter OPC

2. Aerodynamic Particle Sizer: 0.7 - 20  $\mu\text{m}$

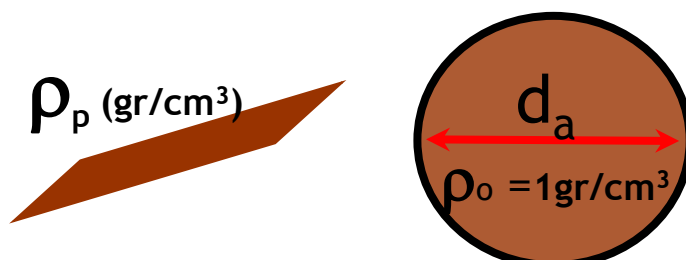


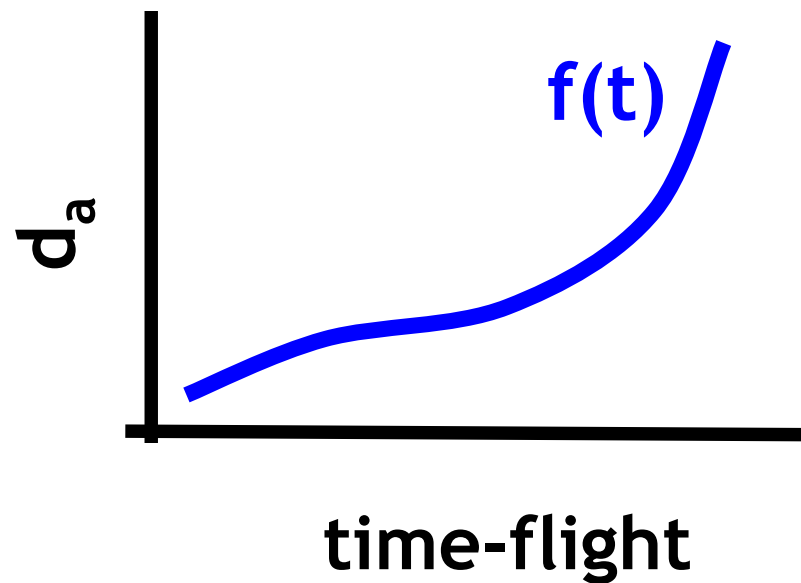
Diagram illustrating the relationship between particle density ( $\rho_p$ ), diameter ( $d_a$ ), and deposition velocity. A particle with diameter  $d_a$  and density  $\rho_o = 1 \text{ gr/cm}^3$  is shown. The deposition velocity is indicated by a downward arrow.

$$V_{TS} = \frac{\rho_p \cdot d_p^2 \cdot g}{18 \eta} = \frac{\rho_o \cdot d_a^2 \cdot g}{18 \eta}$$

$$\rho_p \cdot d^2 = \frac{s \cdot t \cdot 18 \cdot \eta}{a} = \rho_o \cdot d_a^2$$

calibration  $t = f(\rho_p, d)$

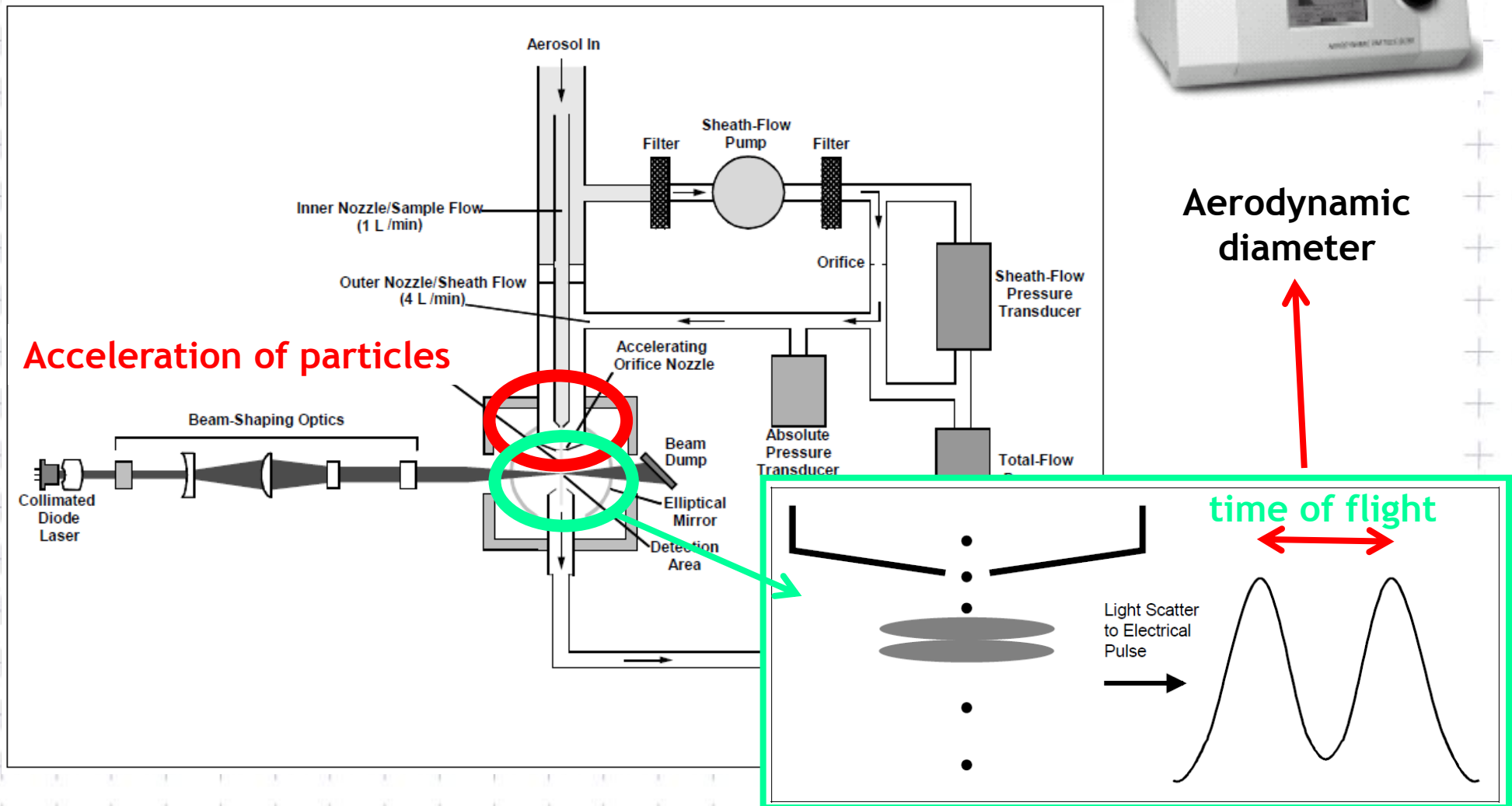
measurement  $d_a = f(t)$



# property of aerosol dust: **number size distribution**

## 1. Optical Particle Counter OPC

## 2. Aerodynamic Particle Sizer: 0.7 - 20 $\mu\text{m}$



# property of aerosol dust: **number size distribution**

## 1. Optical Particle Counter OPC

## 2. Aerodynamic Particle Sizer: 0.7 - 20 $\mu\text{m}$

Potential sources of uncertainties:

Deviations in the sheath / sample flows → inaccuracies in sizing

Characterization of TSP 3321 model, with PLS:

- a counting efficiency of 85% at 0.8  $\mu\text{m}$ , 99% at 3.0  $\mu\text{m}$ , 99% at 5.1  $\mu\text{m}$  and 90% at 9.4  $\mu\text{m}$  (Volckens and Peters, 2005).
- a sizing accuracy of 2 and 3% when measuring spheres of 0.65  $\mu\text{m}$  and 0.96  $\mu\text{m}$  diameter, respectively (Peters and Leith, 2003).
- a 15% instrument-to-instrument variability when sizing 1  $\mu\text{m}$  spheres (Volckens and Peters, 2005).

property of aerosol dust: **number size distribution**

1. Optical Particle Counter OPC: 0.5 - 20  $\mu\text{m}$

2. Aerodynamic Particle Sizer: 0.5 - 20  $\mu\text{m}$

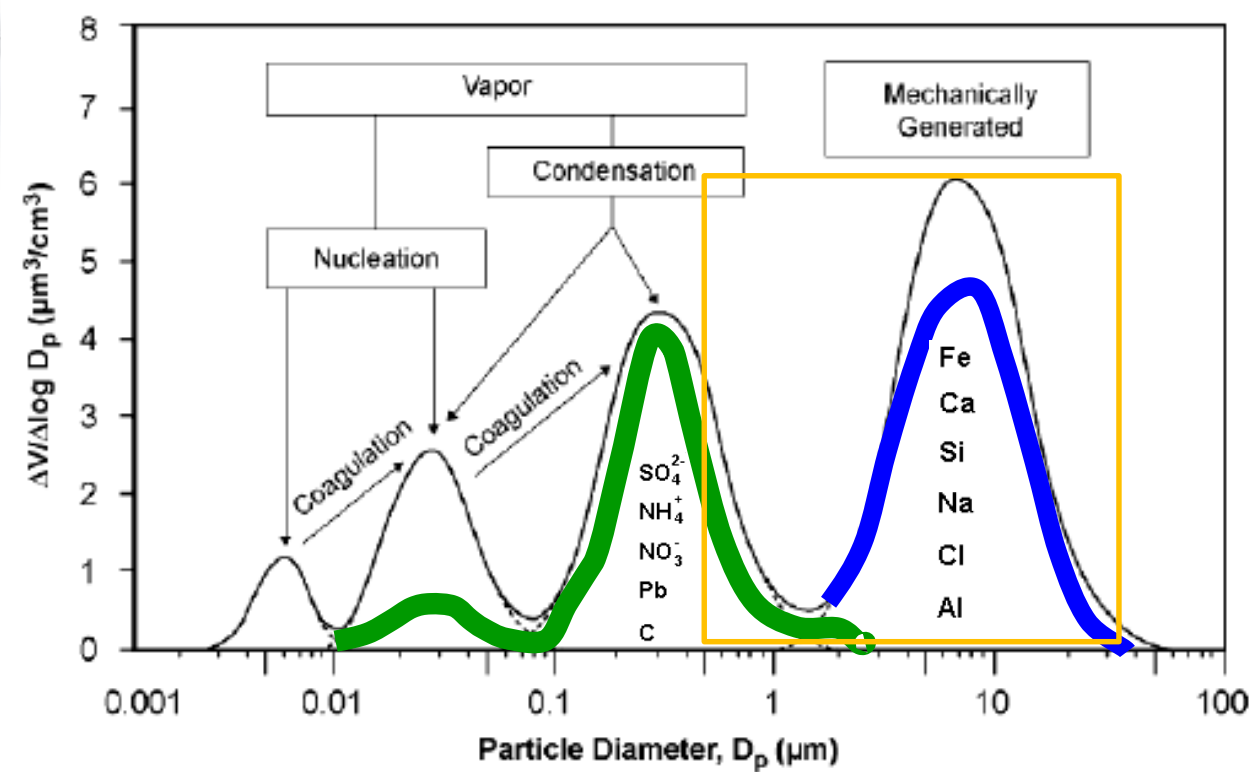
3. Scanning Mobility Particle Sizer: 3 nm - 1  $\mu\text{m}$



$PM_{10}$  (diameter <10 microm)

$PM_{2.5}$

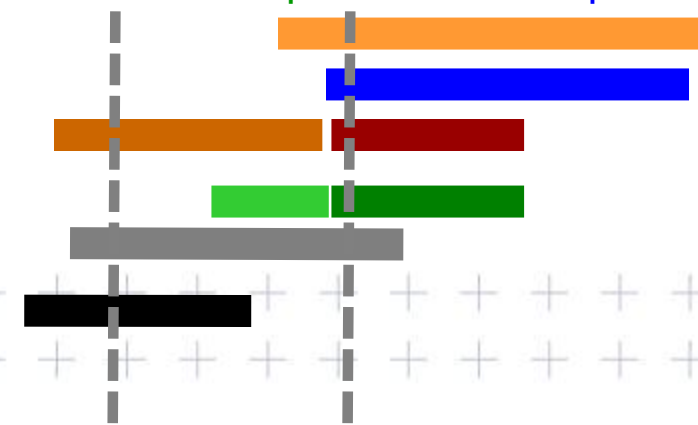
$PM_{2.5-10}$



ultrafine  
<0.1  $\mu m$

accumulation  
0.1 - 1  $\mu m$

Coarse  
1 - 10  $\mu m$



Mineral dust :

Marine salt:

Sulfate:

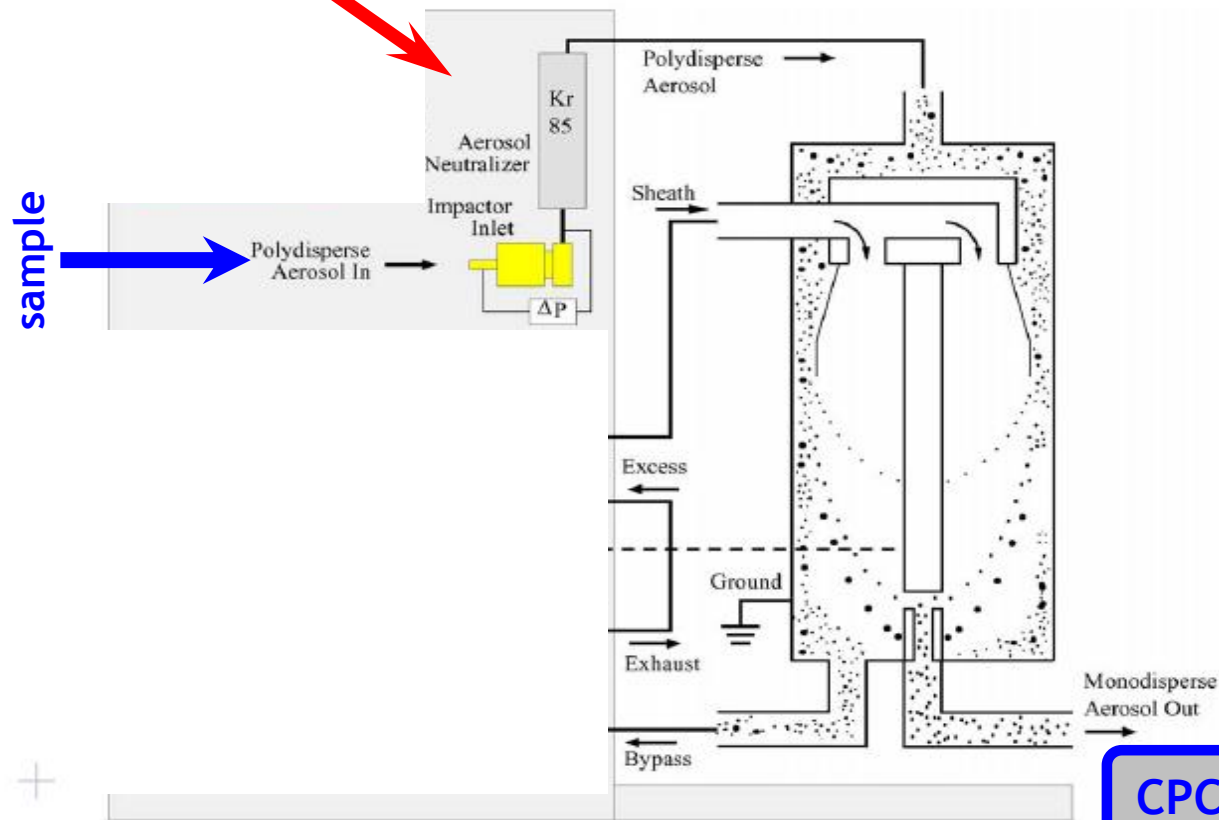
Nitrate:

Organic aerosol:

black carbon:

## Scanning Mobility Particle Sizer: 3 nm - 1 $\mu$ m

### 1. Neutralizer: known charge distribution



## Scanning Mobility Particle Sizer: 3 nm - 1µm

1. Neutralizer: known charge distribution

2. Electrical mobility and selection of particles by size

$$Z_p = \frac{neC}{3\pi\mu D_p}$$

$n$  = number of elementary charges on the particle

$e$  = elementary charge ( $1.6 \times 10^{-19}$  Coulomb)

$C$  = Cunningham slip correction =  
 $1 + Kn[\alpha + \beta \exp(-\gamma/Kn)]$

$\alpha = 1.142$ ,  $\beta = 0.558$ ,  $\gamma = 0.999$  (Allen & Raabe, 1985)

$Kn$  = Knudsen Number =  $2\lambda/D_p$

$\lambda$  = gas mean free path =

$$\lambda_r \left( \frac{P_r}{P} \right) \left( \frac{T}{T_r} \right) \left( \frac{1+S/T_r}{1+S/T} \right)$$

$\mu$  = gas viscosity (dyne • s/cm<sup>2</sup>) poise =

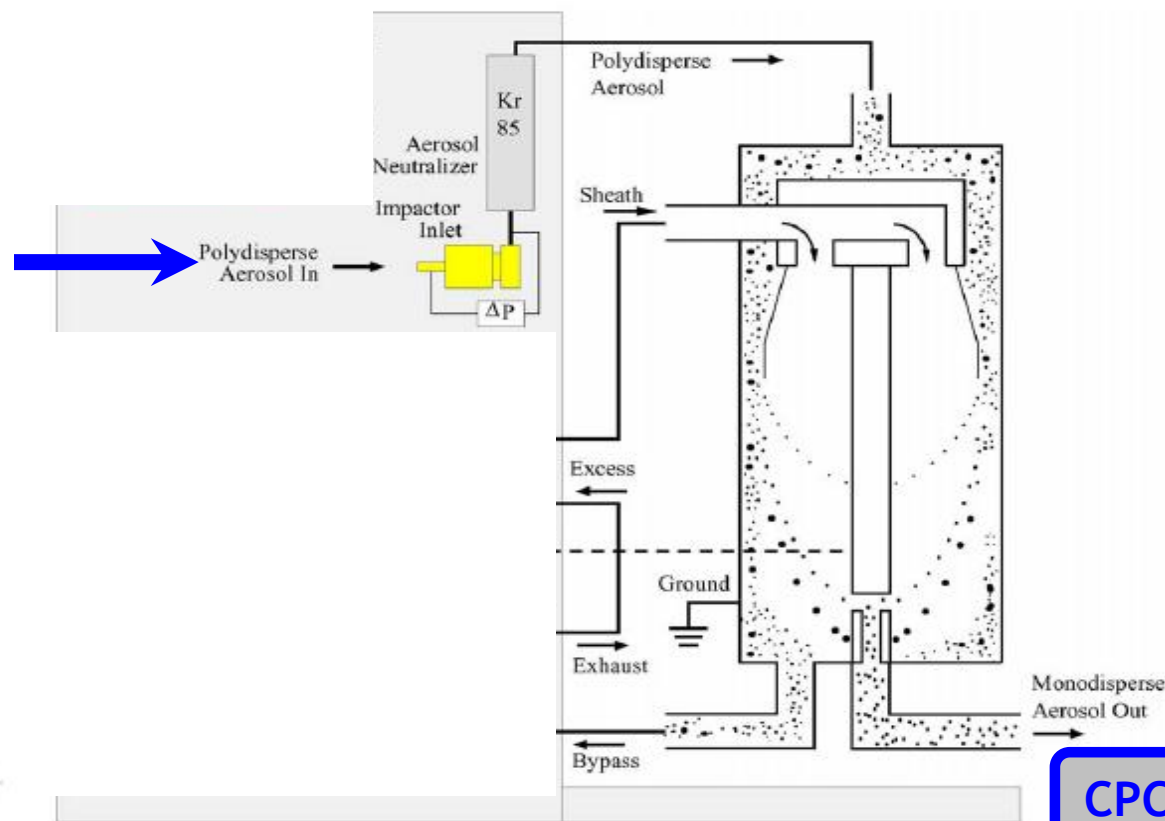
$$\mu_r \left( \frac{T_r + S}{T + S} \right) \left( \frac{T}{T_r} \right)^{\frac{3}{2}}$$

$D_p$  = particle diameter (cm)

$S$  = Sutherland constant [K]

$T$  = temperature [K]

$T_r$  = reference temperature [K]



CPC



# Scanning Mobility Particle Sizer: 3 nm - 1µm

1. Neutralizer: known charge distribution

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$\alpha = 1.142$ ,  $\beta = 0.558$ ,  $\gamma = 0.999$  (Allen & Raabe, 1985)

$Kn$  = Knudsen Number =  $2\lambda/D_p$

$\lambda$  = gas mean free path =

$$\lambda_r \left( \frac{P_r}{P} \right) \left( \frac{T}{T_r} \right) \left( \frac{1+S/T_r}{1+S/T} \right)$$

$\mu$  = gas viscosity (dyne • s/cm<sup>2</sup>) poise =

$$\mu_r \left( \frac{T_r + S}{T + S} \right) \left( \frac{T}{T_r} \right)^{\frac{3}{2}}$$

$D_p$  = particle diameter (cm)

$S$  = Sutherland constant [K]

$T$  = temperature [K]

$T_r$  = reference temperature [K]

$$Z_p^* = \frac{q_{sh}}{2\pi VL} \ln \left( \frac{r_2}{r_1} \right)$$

where:

$Z_p^*$  = set mobility

$q_a$  = aerosol flow rate through the DMA ( $q_a = q_s = q_p$ ;  
for closed-loop setup of sheath and excess flow rate)

$q_s$  = monodisperse flow rate

$q_p$  = polydisperse flow rate

$q_{sh}$  = sheath air flow rate (equal to excess air flow rate)

$r_2$  = outer radius of annular space

= 1.961 cm (for Long DMA)

= 1.905 cm (for Nano DMA)

$r_1$  = inner radius of the annular space

= 0.937 cm (for Long DMA)

= 0.937 cm (for Nano DMA)

$\bar{V}$  = average voltage on the inner center rod (volts)

$L$  = length between exit slit and polydisperse aerosol inlet

= 44.369 cm (for Long DMA\*)

= 4.987 cm (for Nano DMA)

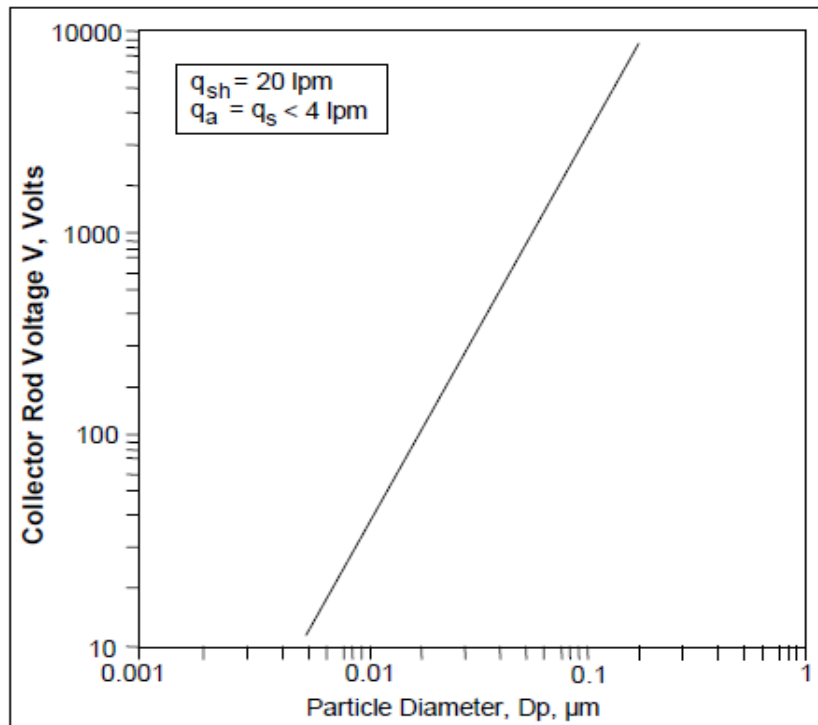


## Scanning Mobility Particle Sizer: 3 nm - 1 $\mu$ m

1. Neutralizer: known charge distribution
2. Electrical mobility and selection of particles by size

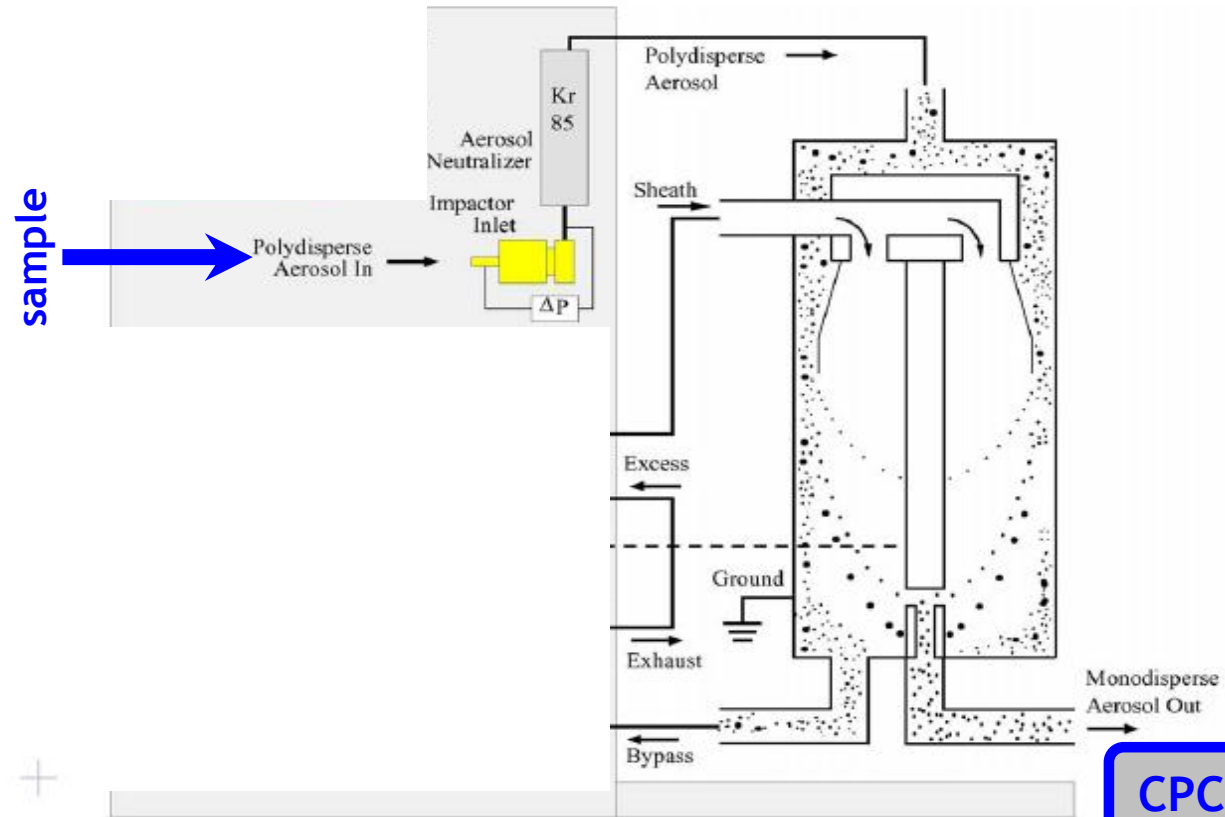
$$Z_p = \frac{neC}{3\pi\mu D_p}$$

$$Z_p^* = \frac{q_{sh}}{2\pi VL} \ln\left(\frac{r_2}{r_1}\right)$$



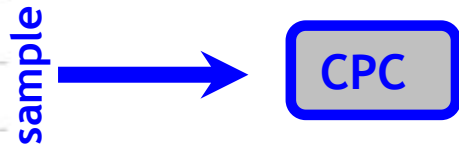
## Scanning Mobility Particle Sizer: 3 nm - 1 $\mu$ m

1. Neutralizer: known charge distribution
2. Electrical mobility and selection of particles by size
3. Counting of monodisperse particles

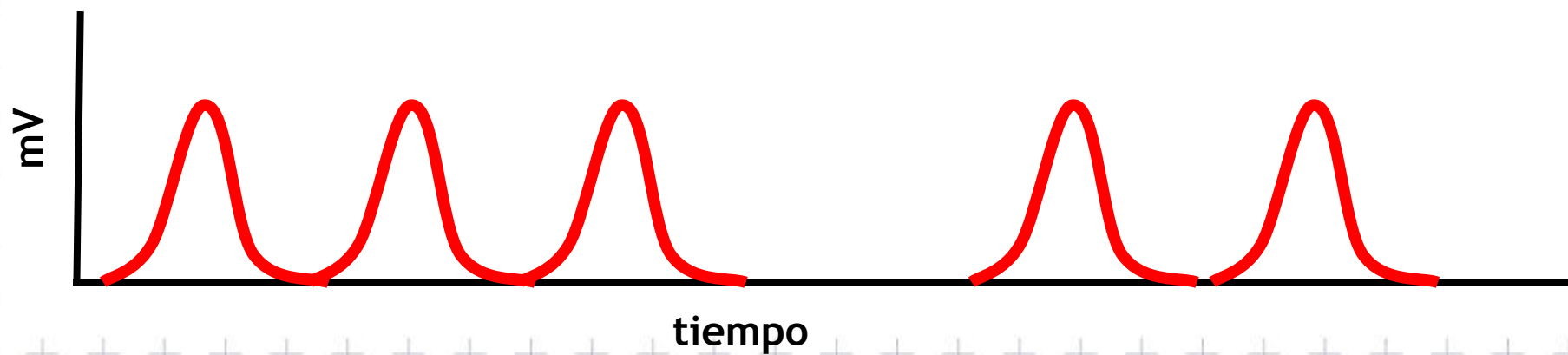
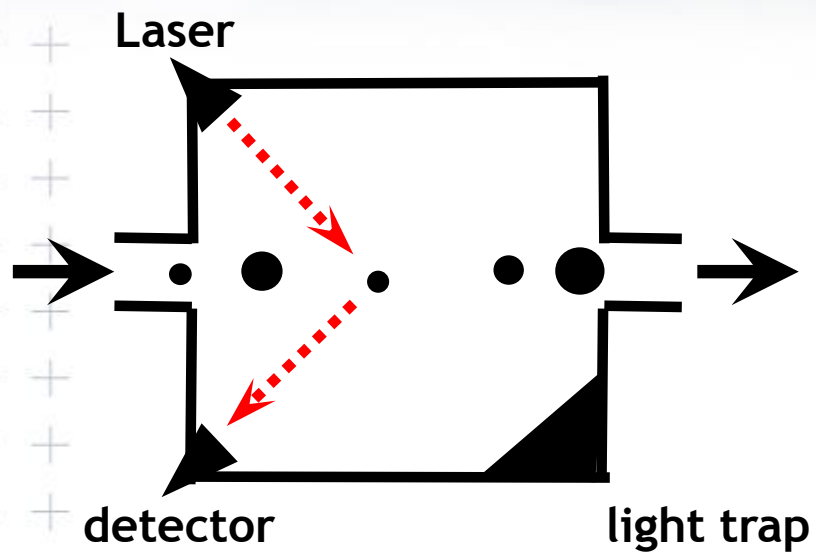


## Scanning Mobility Particle Sizer: 3 nm - 1 $\mu$ m

1. Neutralizer: known charge distribution
2. Electrical mobility and selection of particles by size
3. Counting of monodisperse particles



sample → **CPC**  
**Condensation Particle Counter**

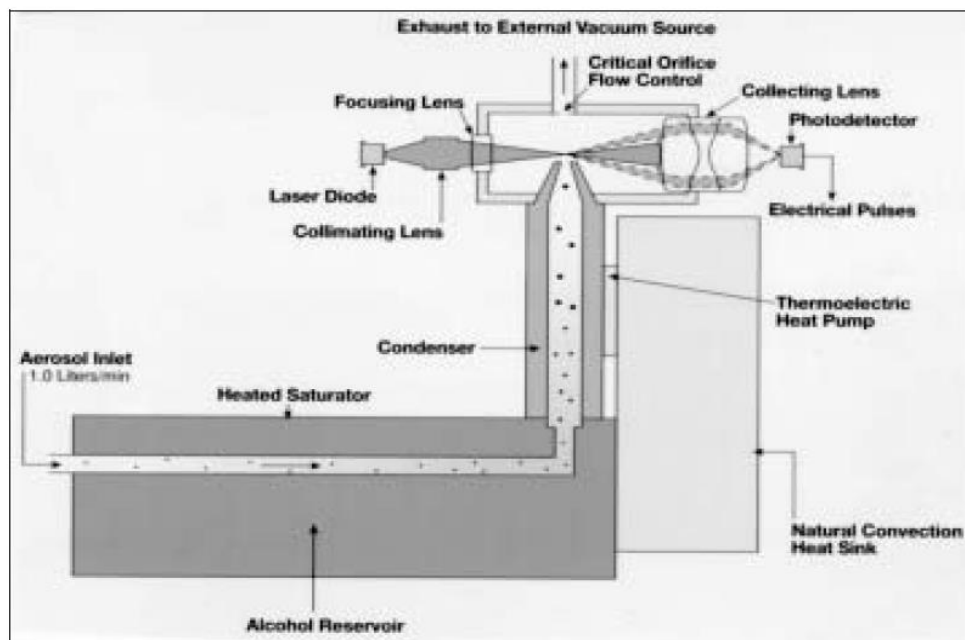


CPC

$\text{cm}^{-3}$

$D_p > 10\text{nm}$

max.  $10^4 - 10^5 \text{ cm}^{-3}$



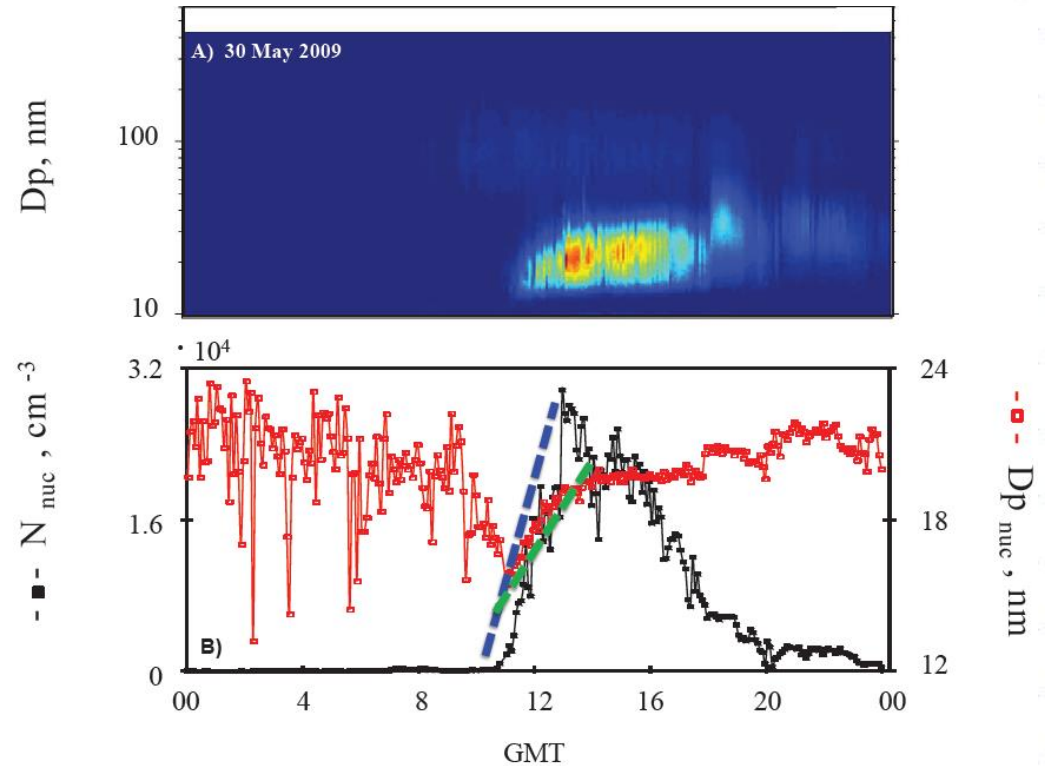


# Concentración en número $\text{cm}^{-3}$

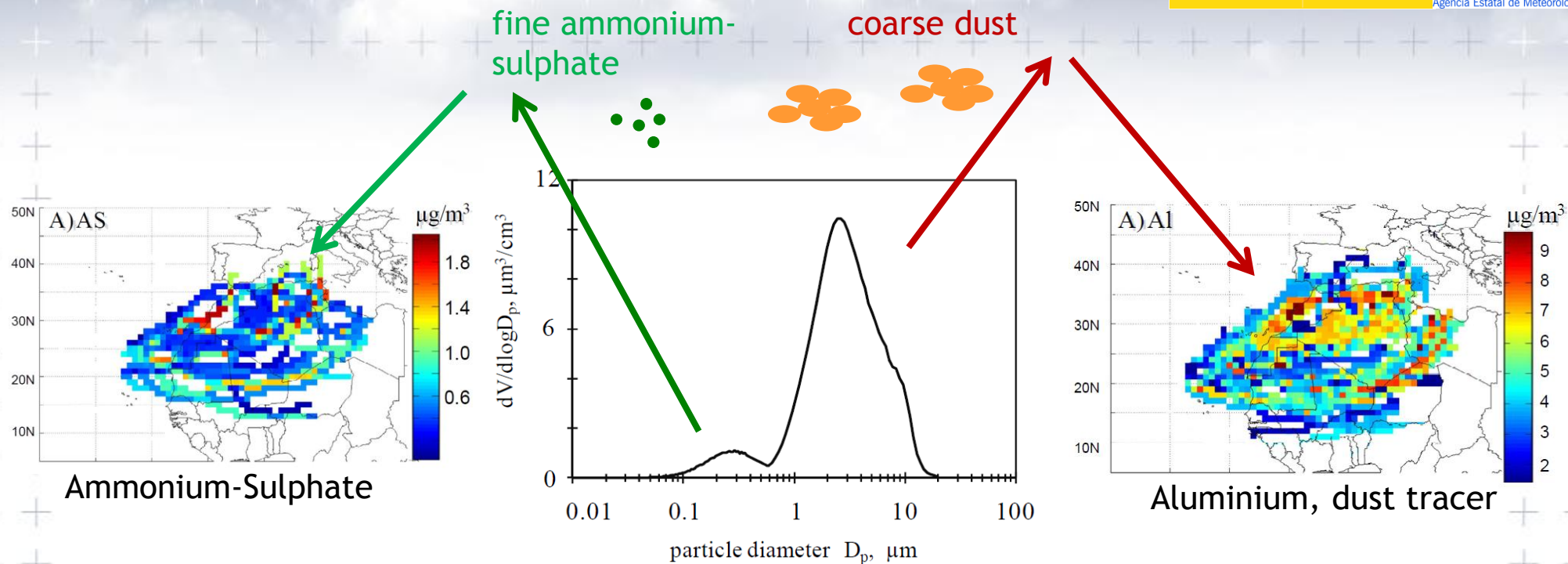


# Izaña

## Scanning Mobility Particle Sizer: 3 nm - 1 $\mu$ m



**Nucleation events: formation of growth of secondary aerosols (usually pollutants, e.g. sulphate)**



Scanning Mobility Particle Sizer

Aerodynamic Particle Sizer

Disadvantage of particle sizers (OPC, APS SMPS): cannot differentiate dust from other particles

## property of aerosol dust:

number size distribution

**mass concentration**

chemical composition

mixing state

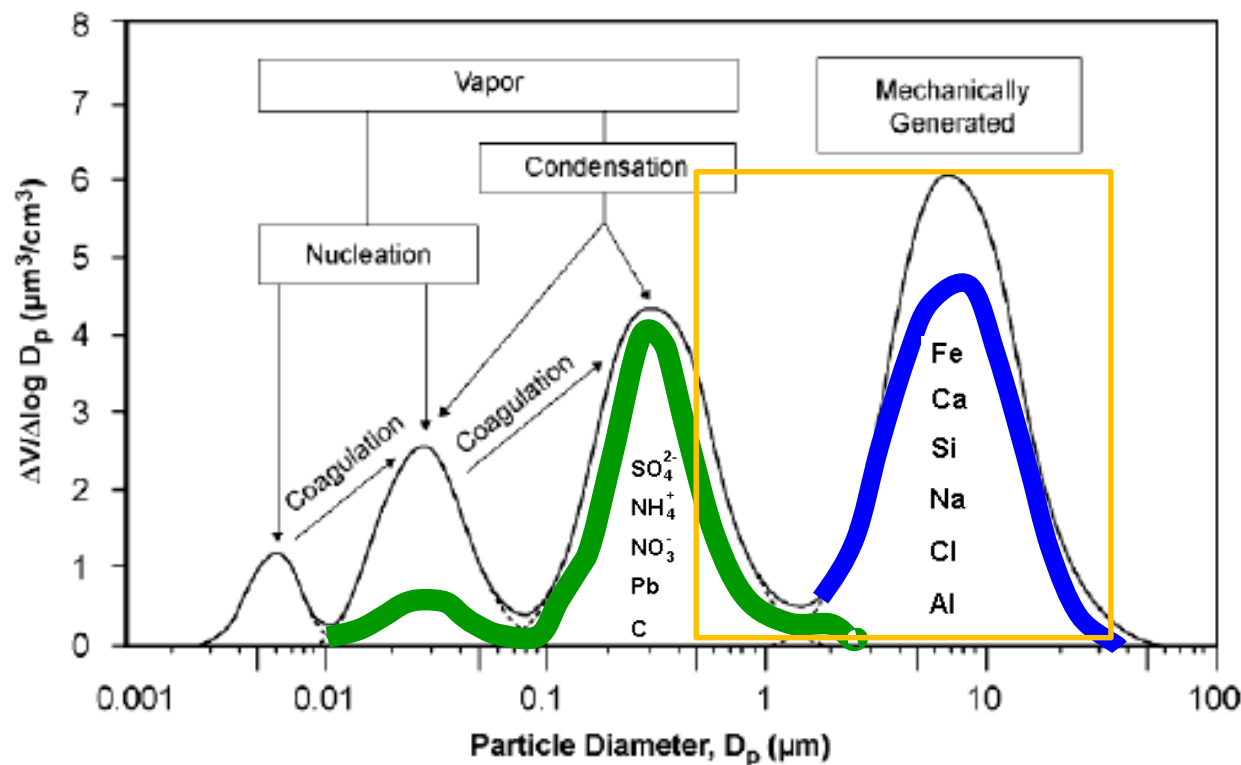
mineralogy

optical properties

$PM_{10}$  (diameter <10 microm)

$PM_{2.5}$

$PM_{2.5-10}$



ultrafine  
<0.1  $\mu m$

accumulation  
0.1 - 1  $\mu m$

Coarse  
1 - 10  $\mu m$

Mineral dust :

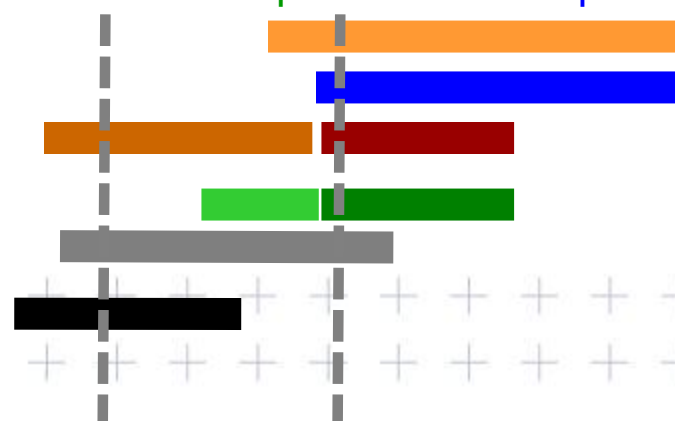
Marine salt:

Sulfate:

Nitrate:

Organic aerosol:

black carbon:





property of aerosol dust: **mass concentration**

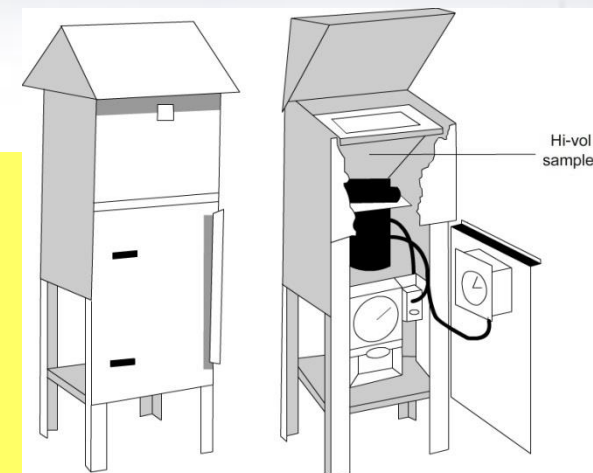
bulk aerosol mass concentration

1. Reference method: gravimetric method
2. Automated analyzers

$PM_{10}$  and  $PM_{2.5}$  measurements in air quality networks

## 1. Reference method: gravimetric method

$$PM = \frac{(W2 - W1)}{\text{Volume}} \quad \mu\text{g}/\text{m}^3$$

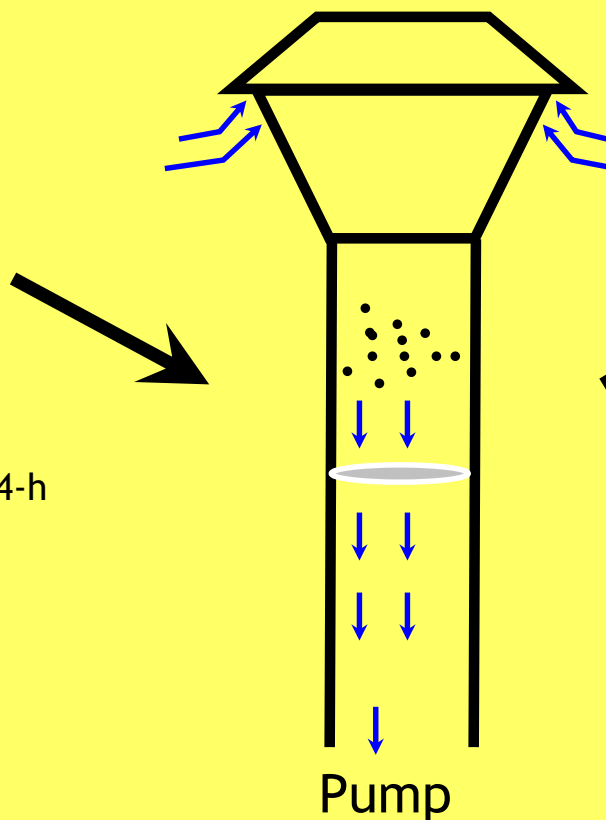


Blank filter

Conditioning

**RH (50±5%)** y T(20±1°C) 24-h

- Filter weight (W1)



Sampled filter

Conditioning

**RH (50±5%)** y T(20±1°C) 24-h

- Filter weight (W2)

## Common Gravimetric Ambient Aerosol Sampling Techniques

- High volume methods: TSP,  $PM_{10}$ ,  $PM_{2.5}$
- Low volume methods: ( $PM_{10}$ ,  $PM_{2.5}$ ,  $PM_{Coarse}$ )

## Micro-Balance room



- Filters conditioning 48-h,  $HR=50\pm5\%$  and  $T=20\pm1^\circ\text{C}$
- balance, LVS resolution  $\geq 5$  digits ( $0.00001\text{g}$ )
- balance, HVS resolution  $\geq 6$  digits ( $0.000001\text{g}$ )

This sample filter is equilibrated at some set of thermodynamic conditions for a period of time before and after sampling. Through the use of a laboratory gravimetric balance, the difference in pre- and post-sample weights yields the PM mass collected. Knowing the volume of air passed through the filter allows the determination of the PM mass concentration.



## PM<sub>10</sub> and PM<sub>2.5</sub> measurements in air quality networks

### 1. Reference method: gravimetric method

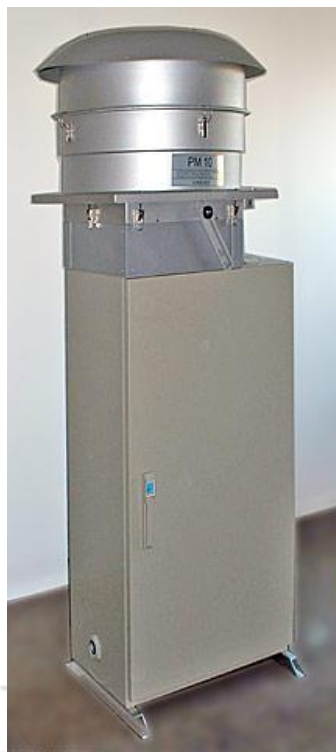
Low Volume Sampler

LVS: **2.3 m<sup>3</sup>/h**



High Volume Sampler

HVS: **68 m<sup>3</sup>/h**



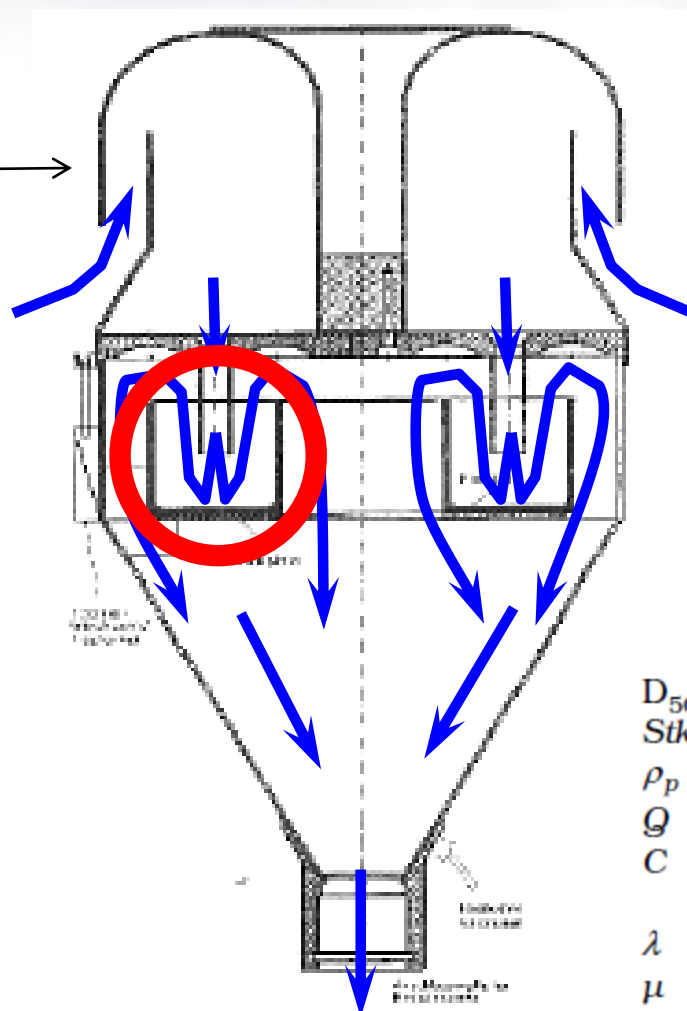
HVS: **30 m<sup>3</sup>/h**



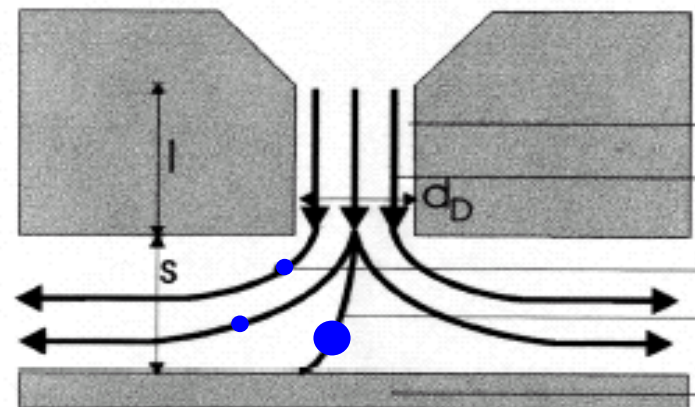


TSP, PM<sub>10</sub>, PM<sub>2.5</sub>, PM<sub>1</sub>:

aerodynamic diameter (as the APS)



Filter



$$D_{50} = \sqrt{\frac{9\pi Stk \mu W^3}{4\rho_p CQ}}$$

$D_{50}$  = particle cut-point diameter centimeter

$Stk$  = Stokes number = 0.23

$\rho_p$  = particle density (g/cm<sup>3</sup>)

$Q$  = volumetric flow rate (cm<sup>3</sup>/s)

$C$  = Cunningham slip correction

=  $1 + 2.492 \lambda/D_{50} + 0.84 \lambda/D_{50} \exp(-0.435 D_{50}/\lambda)$

$\lambda$  = gas mean free path

$\mu$  = gas viscosity (dyne•s/cm<sup>2</sup>)

$W$  = nozzle diameter (cm)

The Stokes number is a dimensionless parameter that characterizes impaction.

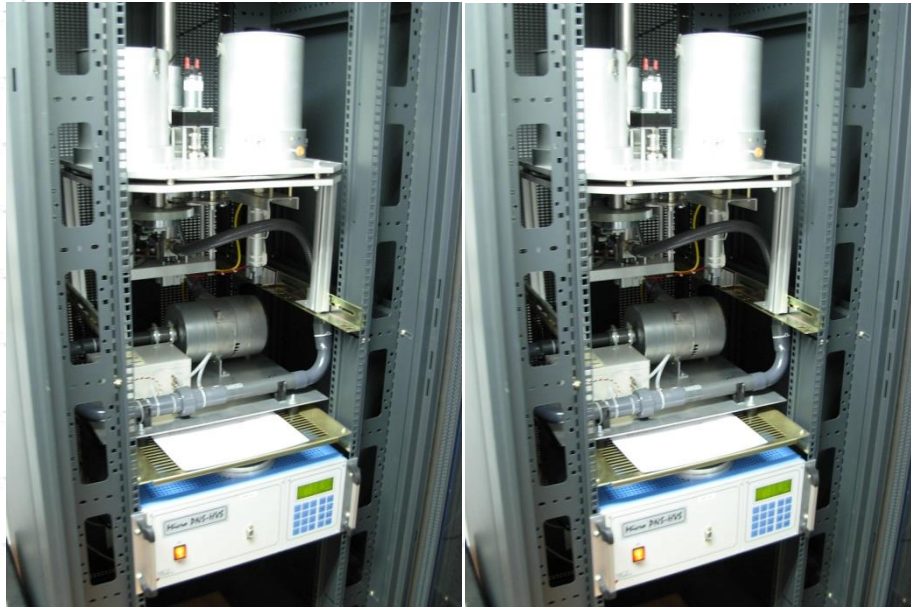
## Complete PM gravimetric method set-up at Izana Atmospheric Research Center

Weight filters conditioned room



PM<sub>10</sub>

PM<sub>2.5</sub>



## Common Gravimetric Ambient Aerosol Sampling Techniques

- Advantages: Recognized reference method, low capital cost
- Disadvantages: Limited time resolution (typically 24-hr), long turnaround times, labor intensive, and gravimetric lab maintenance/cost

## Common Continuous Ambient Aerosol Sampling Techniques

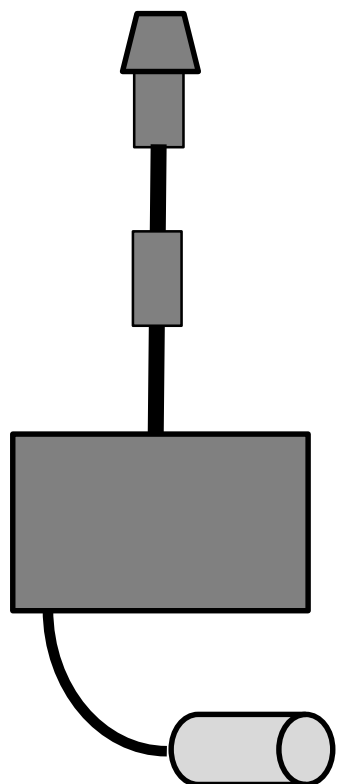
$$(Dm / Dt) / (DV / Dt) = \text{mg/m}^3$$

- Tapered Element Oscillating Microbalance
- Beta (Electron) Attenuation



$PM_{10}$  and  $PM_{2.5}$  measurements in air quality networks

## 2. Automated analyzers



1. Impactor  $PM_{10}$  /  $PM_{2.5}$

2. RH reductor / heater

3. Sensor (Beta radiation attenuation or Tapered Oscillating microbalance-TEOM-) → instead of weighting filters

4. Pump / Flow meter

Continuous measurements of PM ( $PM_{10}$ ,  $PM_{2.5}$ ,  $PM_1$  or TSP)



## Mass concentration

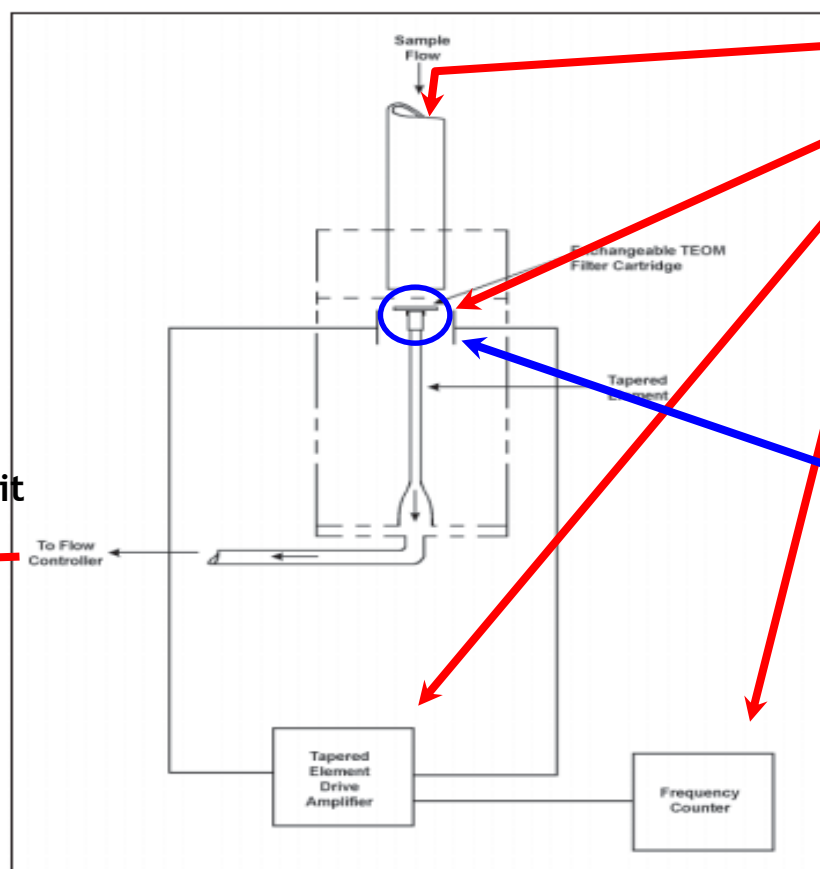
Automatic continuous measurements

## TEOM : Tapped Element Oscillating Microbalance

### 1. TEOM mod.1400a

mass=function (frequency)

sensor



Sampling flow rate (16.67 l/m)

Sample accumulated in the filter

Micro-oscilation of constante amplitue  
GENERATOR

Frequency sensor

An increase in the amount of sample  
(dust) accumulated in the filter →  
decrease in the oscillation frequency

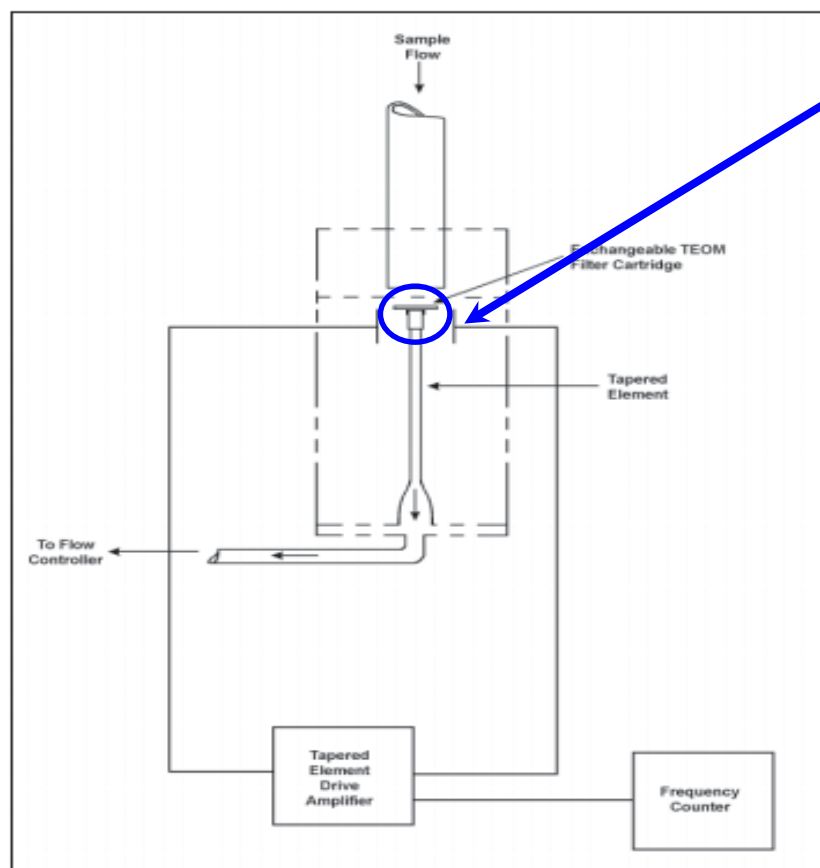
## Mass concentration

Automatic continuous measurements

## TEOM :Tapped Element Oscillating Microbalance

### 1. TEOM mod.1400a

sensor



mass=function (frequency)

more dust → lower oscillation frequency

In a spring-mass system the frequency follows the equation:

$$f = (K / M)^{0.5}$$

where:

$f$  = frequency (radians/sec)

$K$  = spring rate

$M$  = mass

$K$  and  $M$  are in consistent units. The relationship between mass and change in frequency can be expressed as:

$$dm = K_0 \left( \frac{1}{f_1^2} - \frac{1}{f_0^2} \right) \quad (2)$$

where:

$dm$  = change in mass

$K_0$  = spring constant (including mass conversions)

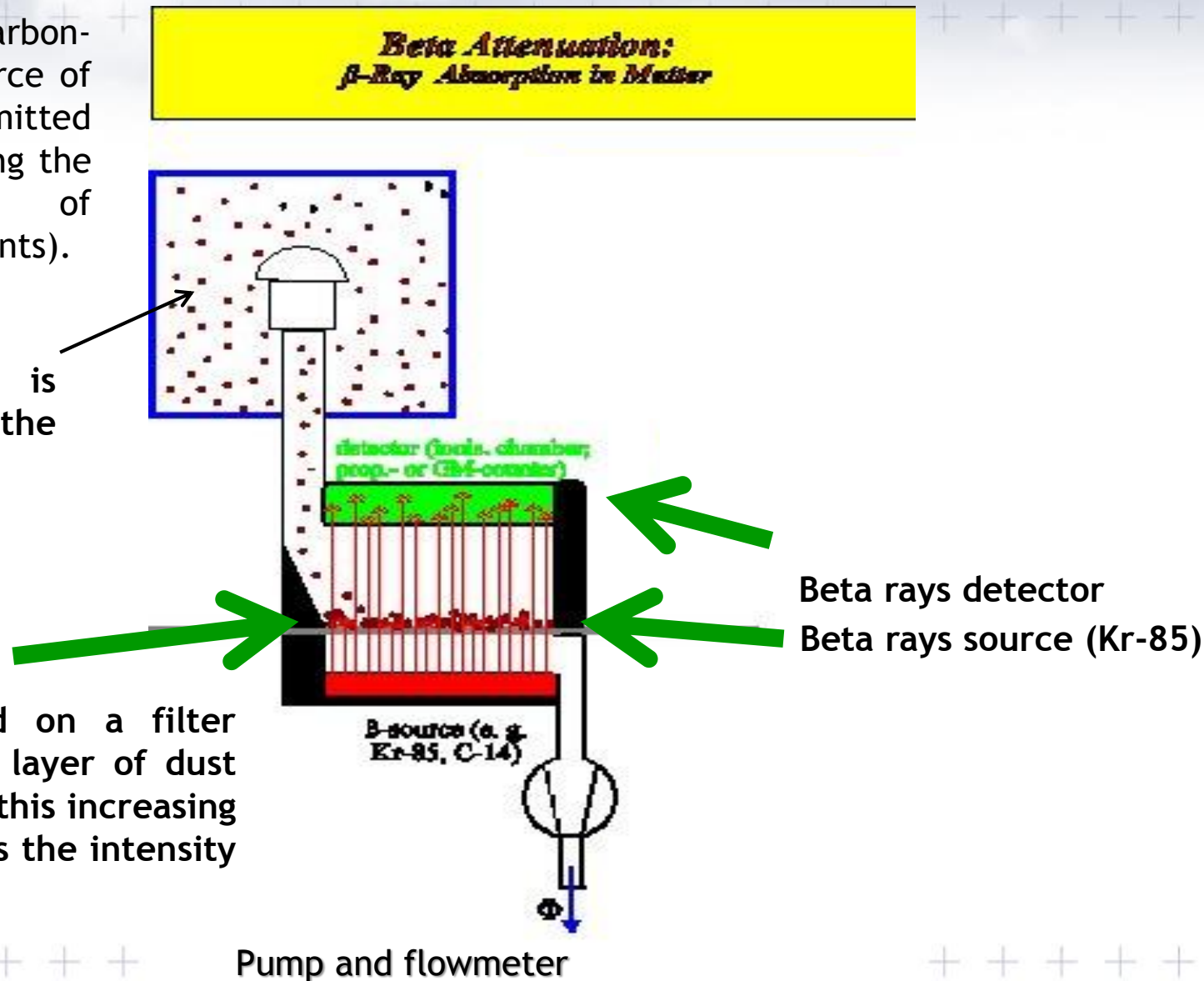
$f_0$  = initial frequency (Hz)

$f_1$  = final frequency (Hz)

Krypton-85 or Carbon-14 is used as source of beta radiation (emitted by electrons during the nuclear decay of radioactive elements).

Ambient air is drawn through the sample system

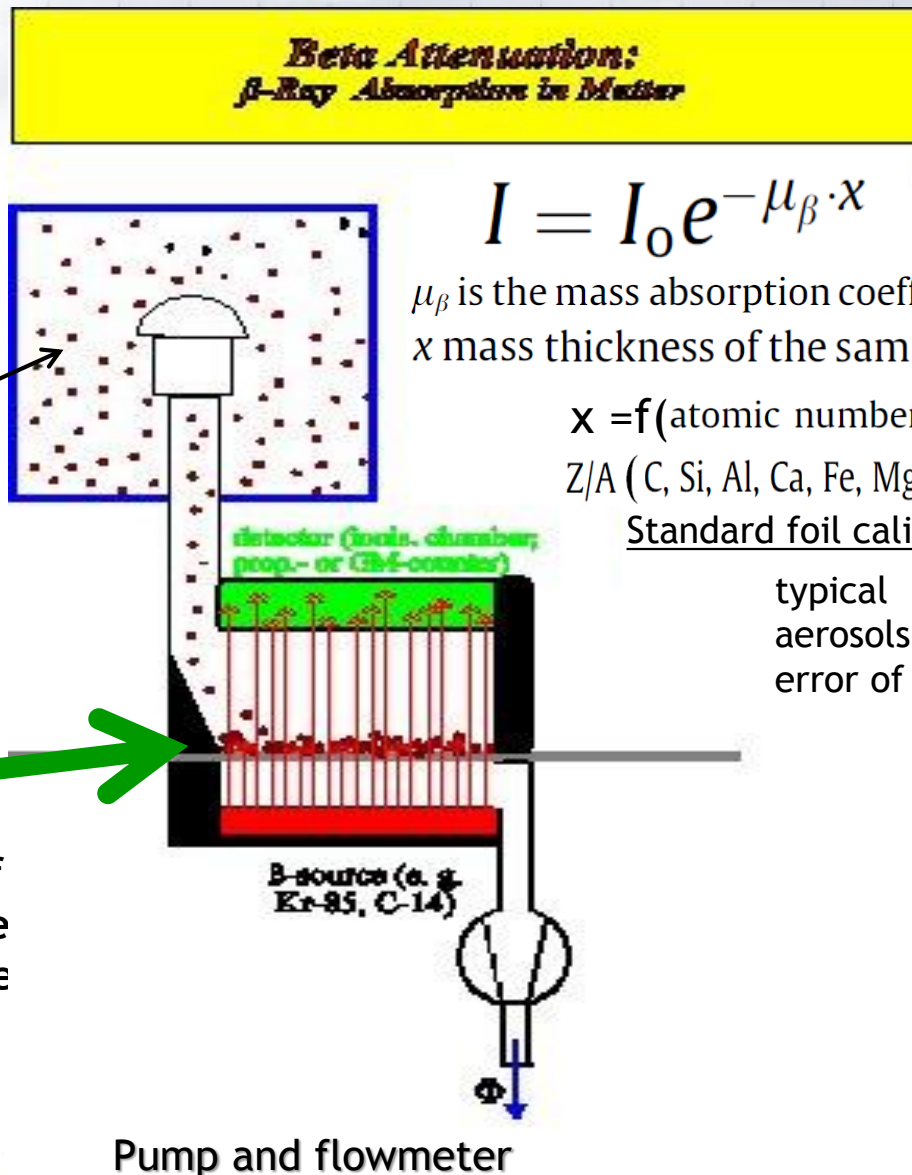
Dust is deposited on a filter continuously. The layer of dust is building up and this increasing dust mass weakens the intensity of the beta beam.



Krypton-85 or Carbon-14 is used as source of beta radiation (emitted by electrons during the nuclear decay of radioactive elements).

Ambient air is drawn through the sample system

Dust is deposited on a continuously. The layer of is building up and this incre dust mass weakens the inte of the beta beam.



## PM with Beta attenuation (2)

$$m = F_{cal} \ln \left( \frac{I_0}{I} \right)$$

- **m**: increasing particle mass [ $\mu\text{g}$ ]
- **F<sub>cal</sub>**: calibration factor
- **I<sub>0</sub>** beta ray intensity at empty filter
- **I** beta ray intensity at loaded filter

The intensities  $I_0$  and  $I$  are measured with the detector system.  $F_{cal}$  has to be measured directly during the calibration procedure. This is accomplished by replacing the filter with the element having a known mass (mass calibration kit)

The mass concentration is calculated from:

$$c = \frac{m}{Ft}$$

Where:

c: concentration [ $\mu\text{g}/\text{m}^3$ ]

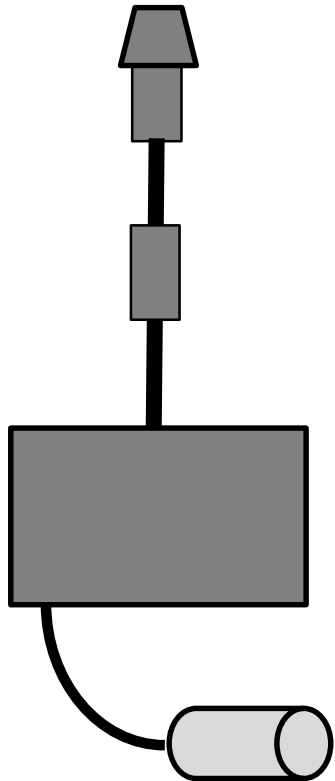
F: measured air flow [ $\text{m}^3/\text{h}$ ]

t: time [h]



$PM_{10}$  and  $PM_{2.5}$  measurements in air quality networks

## 2. Automated analyzers



beta

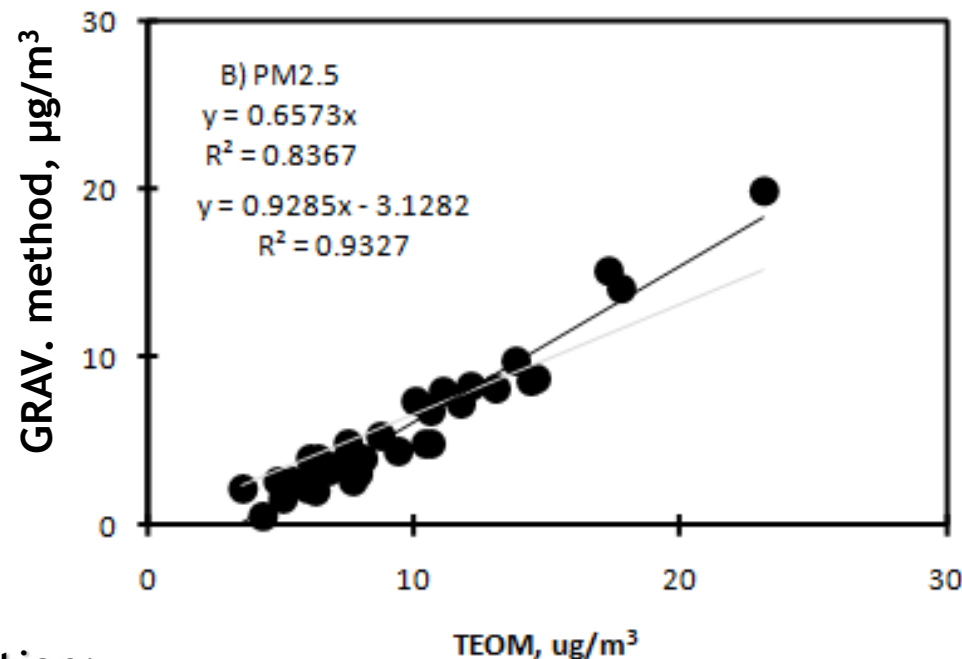
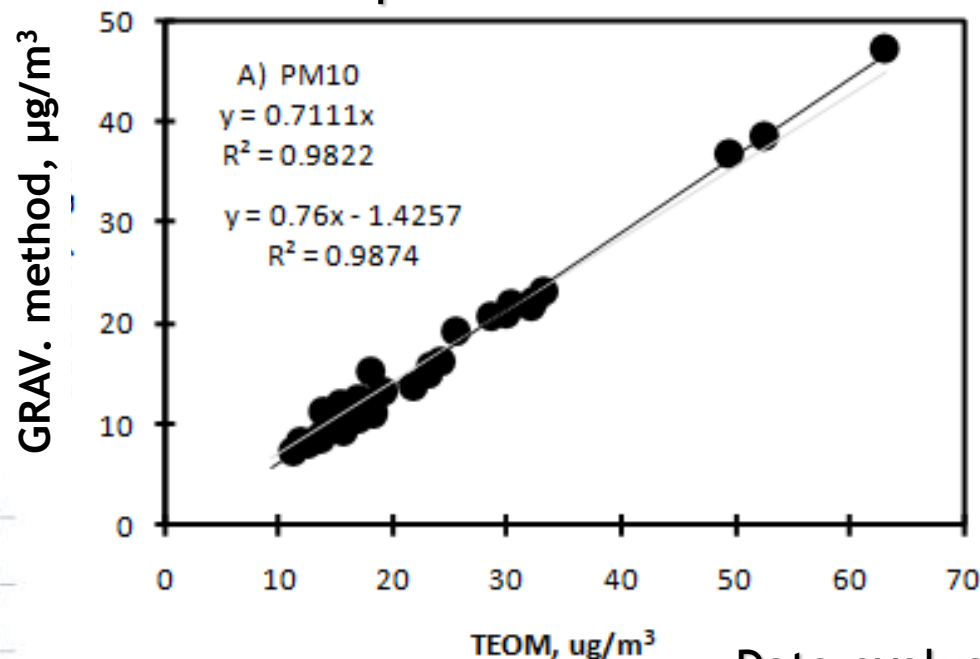


TEOM

## Automatic versus the reference gravimetric method

Conversion of the 'automatic PM<sub>10</sub> and PM<sub>2.5</sub>' data to GRAVIMETRIC EQUIVALENT data

### Intercomparisons



### Data evaluation:

Data from continuous analyzer are valid if they fit A or B:

A)  $Y = a \cdot X$ ;  $r^2 \geq 0.8$

B)  $Y = a \cdot X + b$ ;  $r^2 \geq 0.8$ ;  $\text{abs}(b) < 5$

Y= Reference Method (gravimetric method),

X= Automatic analyzer

## Common Continuous Ambient Aerosol Sampling Techniques

$$(Dm / Dt) / (DV / Dt) = \text{mg/m}^3$$

### *Advantages*

- Continuous method
- Highly time resolved
- High resolution
- instantaneous turnaround
- Low operational cost

### *Disadvantages*

Temperature dependency:

- Volatile losses

- Seasonal and regional dependencies

- Affected by vibration

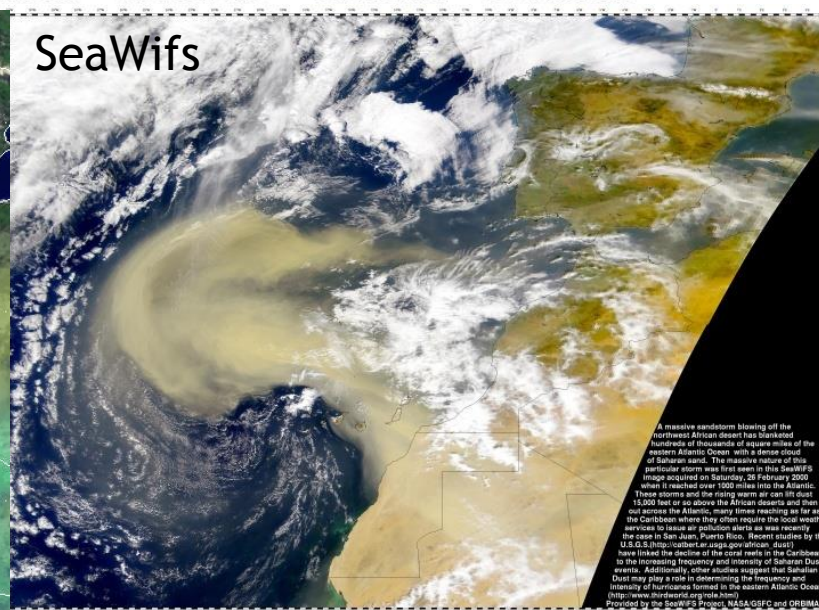
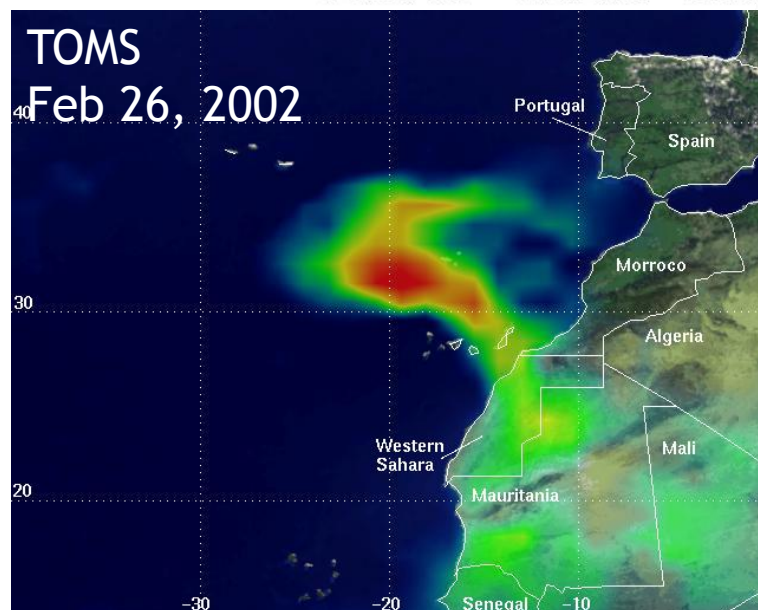
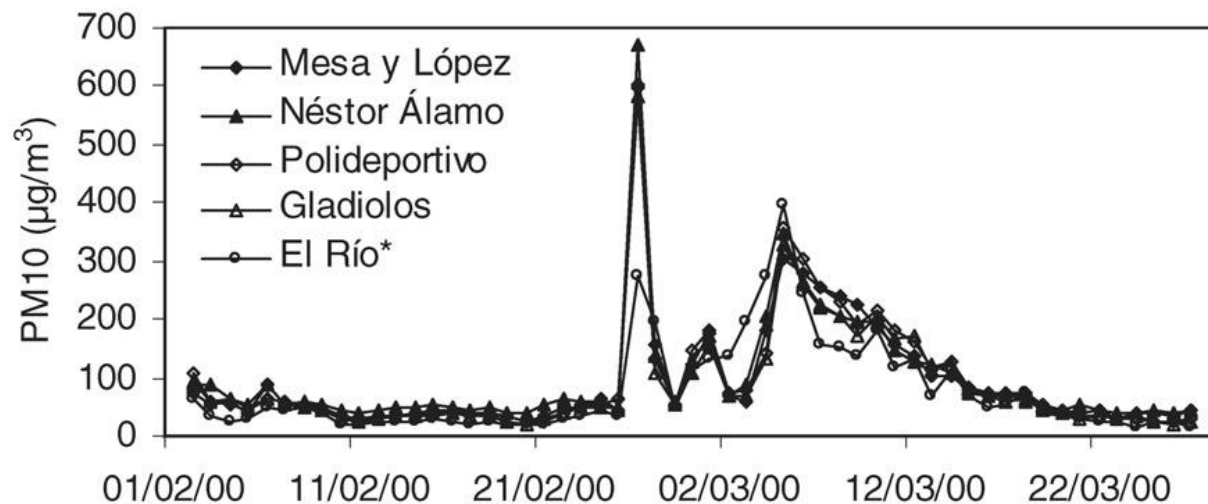
- Manual filter changes necessary

- Complex systems require some skill

- X2 or X3 capita cost

- Determination of Gravimetric Equivalent concentrations

Air quality stations at Tenerife Island

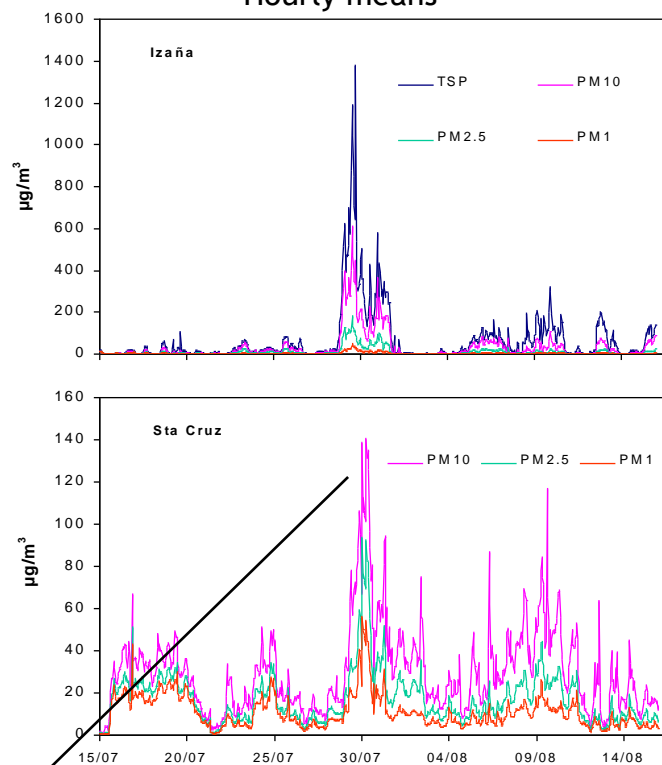


Viana et al., Atmospheric Environment, 2002

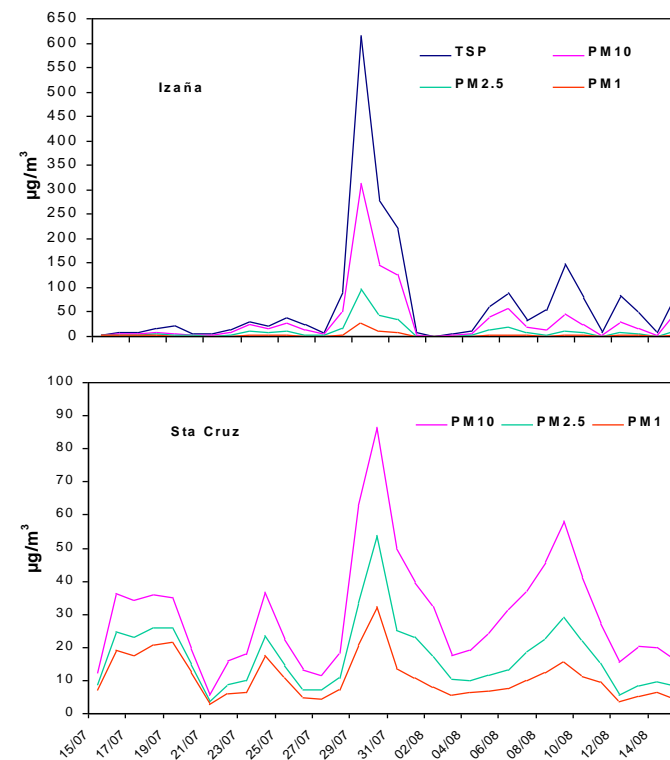


# In-situ dust characterization

## Hourly means



## Daily means





property of aerosol dust: **mass concentration**

bulk aerosol mass concentration

**bulk dust mass concentration**

## bulk dust mass concentration

### method-1 : filter ash (J.M. Prospero)

step-1: samples collected on filters are extracted with de-ionized water and the extracts are analyzed for major soluble inorganic ions:

- Na<sup>+</sup> by flame atomic absorption
- Cl<sup>-</sup>, NO<sub>3</sub><sup>-</sup> and SO<sub>4</sub><sup>=</sup> by suppressed ion chromatography
- NH<sub>4</sub><sup>+</sup> by automated colorimetry

step-2: then, non sea salt sulfate is calculated using the SO<sub>4</sub><sup>=</sup>/Na<sup>+</sup> ratio in bulk sea water (0.2517).

$$\text{sea salt} = \text{Na}^+ + \text{ss-SO}_4^= (0.2517 \cdot \text{Na}^+)$$

step-3: the extracted filters are then placed in a muffle furnace for 14-h (overnight) at 500° C. The ash residue weight.

$$\text{bulk dust} = \frac{\text{weight ash residue}}{\text{volume of sampled air}} \times 1.3$$

normalization: Al accounts for 8% of dust

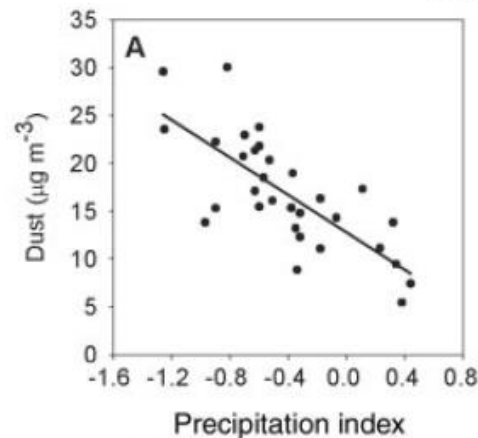
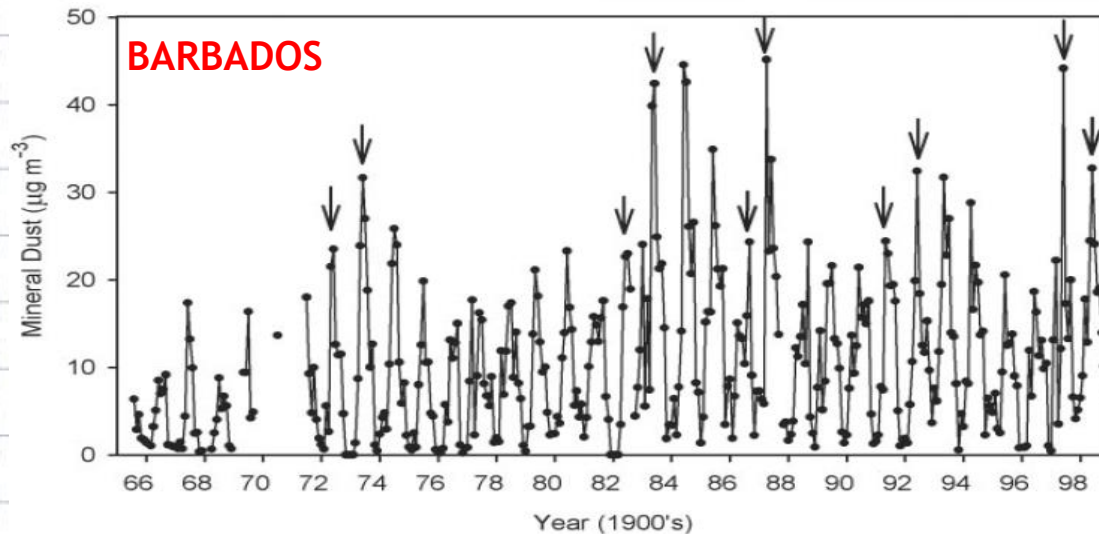
this technique may underestimate dust concentrations because of the loss of soluble minerals (carbonates, halides).

-standard error is considered:  $\pm 0.1 \mu\text{g}/\text{m}^3$  for concentrations  $< 1 \mu\text{g}/\text{m}^3$   
10% for higher concentrations.



## method-1 : filter ash (J.M. Prospero)

Longest records of dust: since 1964



(A) Dust plotted against the prior-year

## African Droughts and Dust Transport to the Caribbean: Climate Change Implications

Joseph M. Prospero<sup>1\*</sup> and Peter J. Lamb<sup>2</sup>

7 NOVEMBER 2003 VOL 302 SCIENCE



Review Article

Aeolian Research

Aeolian Research 6 (2012) 55–74

A review of methods for long term in situ characterization of aerosol dust

Sergio Rodríguez<sup>a,\*</sup>, Andrés Alastuey<sup>b</sup>, Xavier Querol<sup>b</sup>

## bulk dust mass concentration method-2: tracer analysis

In a filter with the dust sample, one or more dust tracer are analysed by chemical methods, and then total dust is calculated using the mean proportion of that element in dust:

$$\text{Al (8\% of soil)} \longrightarrow \text{dust} = \text{Al} \cdot (100/8) \quad \text{Eq-1}$$

$$\text{Si (33\% of soil)} \longrightarrow \text{dust} = \text{Si} \cdot (100/33) \quad \text{Eq-2}$$

ratio element / oxide

**Na2O** 0.47

**MgO** 0.43

**Al2O3** 1.89

**SiO2** 5.98

**K2O** 0.38

**CaO** 0.62

**TiO2** 0.09

**Fe2O3** 0.88

stoichiometry

$$\text{dust} = 0.47 \cdot \text{Na} + 0.43 \cdot \text{Mg} + 1.89 \cdot \text{Al} + 5.98 \cdot \text{Si} + 0.38 \cdot \text{K} + 0.62 \cdot \text{Ca} + 0.88 \cdot \text{Fe} + 0.09 \cdot \text{Ti} \quad \text{Eq-3}$$

Can be applied with elements  
with low enrichment factor!!!!





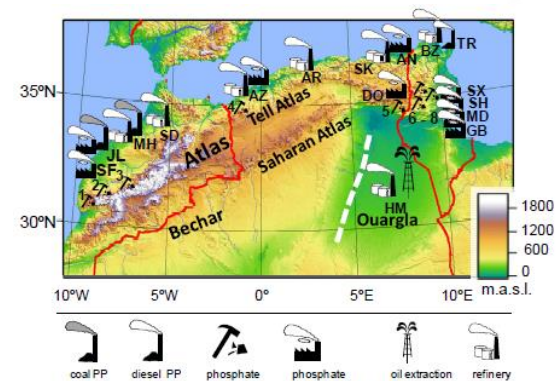
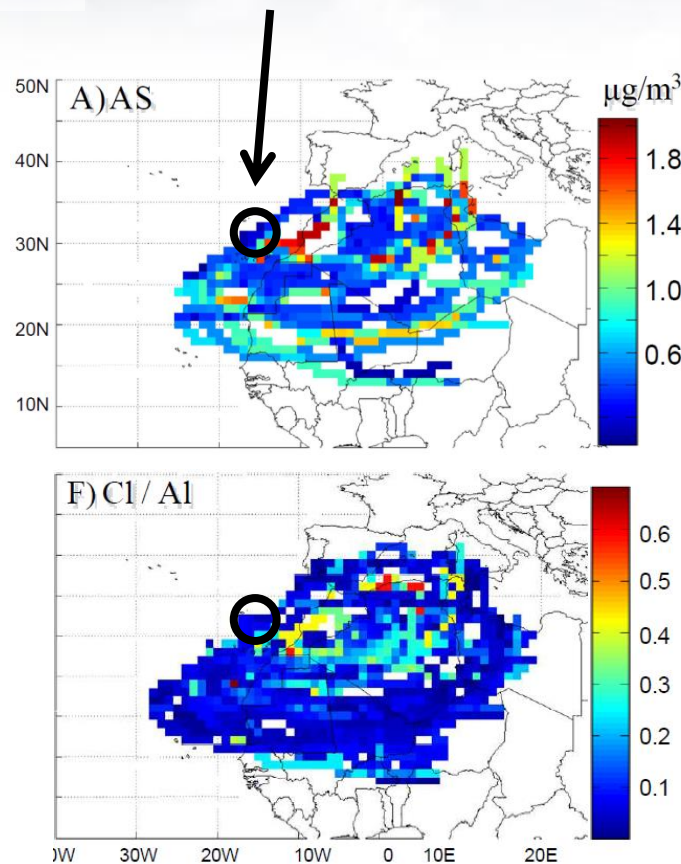
## bulk dust mass concentration method-2: tracer analysis

Izaña - Tenerife

	EF
Al	1.00
Ca	0.97
K	0.72
Na	0.31
Mg	0.78
Fe	0.85
S	35.71
Cl	77.70
P	0.70
Ni	0.56



Izaña: measurement site



S and Cl<sup>-</sup> emitted  
by industry mixed  
with dust

## Transport of desert dust mixed with North African industrial pollutants in the subtropical Saharan Air Layer

S. Rodríguez<sup>1</sup>, A. Alastuey<sup>2</sup>, S. Alonso-Pérez<sup>1,2</sup>, X. Querol<sup>2</sup>, E. Cuevas<sup>1</sup>, J. Abreu-Afonso<sup>1</sup>, M. Viana<sup>2</sup>, N. Pérez<sup>2</sup>,  
M. Pandolfi<sup>2</sup>, and J. de la Rosa<sup>3</sup>

Atmos. Chem. Phys., 11, 6663–6685, 2011  
www.atmos-chem-phys.net/11/6663/2011/  
doi:10.5194/acp-11-6663-2011  
© Author(s) 2011. CC Attribution 3.0 License.



## property of aerosol dust:

number size distribution

mass concentration

**chemical composition**

mixing state

mineralogy

optical properties

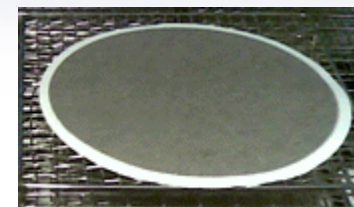
## bulk chemical composition

PM samples:  $\left\{ \begin{array}{l} \text{fine + coarse (TSP, PM}_{10}\text{)} \\ \text{fine (PM}_{2.5}\text{, PM}_1\text{)} \end{array} \right.$

## Saharan dust



## Urban particles



PM ( $\mu\text{g}/\text{m}^3$ ) = **dust** + **trace elements** + **ions** ( $\text{SO}_4^{=}$ ,  $\text{NO}_3^-$ ,  $\text{NH}_4^+$ ,  $\text{Na}^+$ ,  $\text{Cl}^-$ ) + OC + EC

## Elemental Composition:

Major elements (Al, Si, Ca, K, Na, Mg) + trace elements (P, Li, Be, Sc, Ti, V, Cr, Mn, Co, Ni, Cu, Zn, Ga, Ge, As, Se, Rb, Sr, Y, Zr, Nb, Mo, Cd, Sn, Sb, Cs, Ba, La, Ce, Pr, Nd, Sm, Eu, Gd, Tb, Dy, Ho, Er, Tm, Yb, Lu, Hf, Ta, W, Tl, Pb, Bi, Th, U)

Inductively coupled plasma  
**Atomic Emission Spectroscopy**  
ICP-AES

Inductively coupled plasma  
**Mass spectroscopy**  
IPC-MS

**Destructive techniques**

**XRF, PIXE, INAA : none destructive techniques**

**Ions:**  $\text{SO}_4^{=}$ ,  $\text{NO}_3^-$ ,  $\text{NH}_4^+$ ,  $\text{Na}^+$ ,  $\text{Cl}^-$

**Ion Chromatography, ICP-AES, ICP-MS, selective electrodes and colorimetry**

**Destructive techniques**

**Thermal/optical reflectance (TOR) and/or thermal/optical transmission (TOT)**

**destructive techniques**

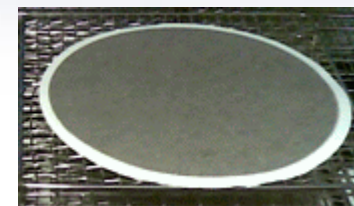
## bulk chemical composition

PM samples:  $\left\{ \begin{array}{l} \text{fine + coarse (TSP, PM}_{10}\text{)} \\ \text{fine (PM}_{2.5}\text{, PM}_1\text{)} \end{array} \right.$

Saharan dust



Urban particles

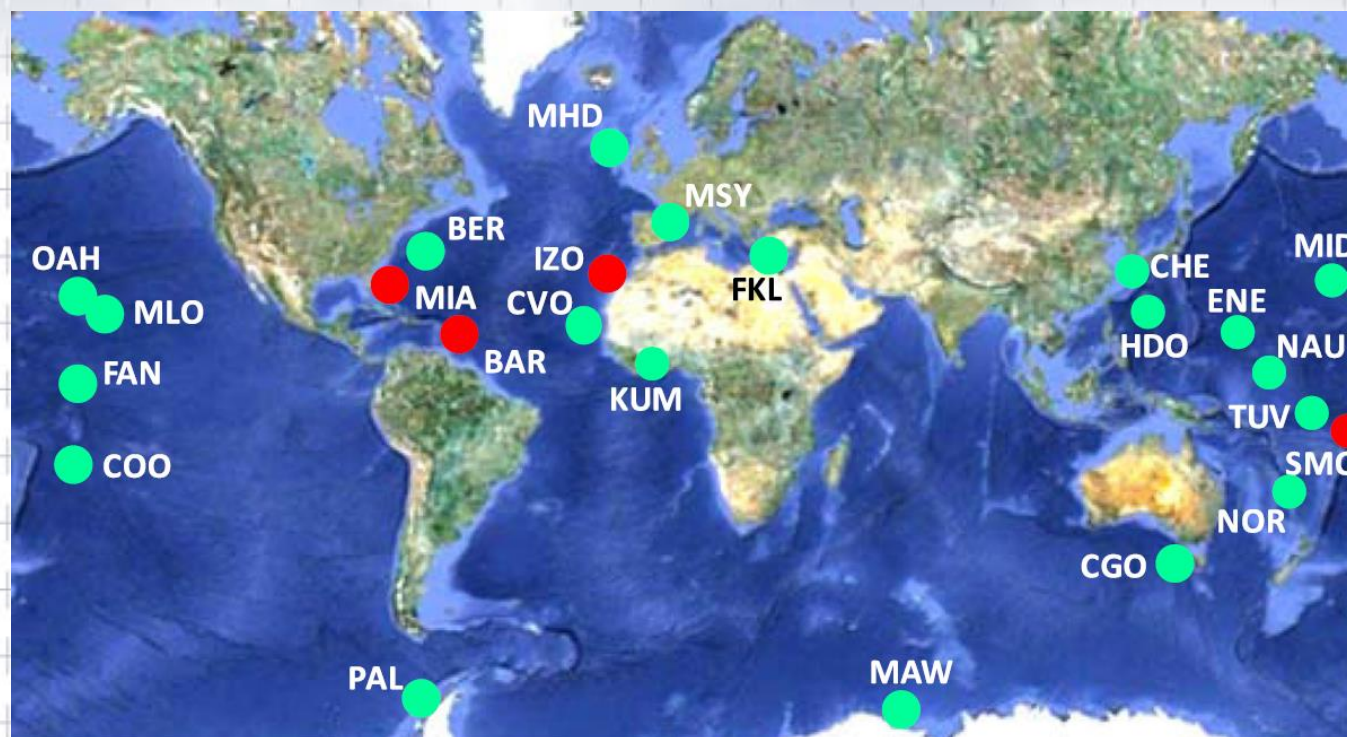




PM ( $\mu\text{g}/\text{m}^3$ ) = **dust** + **ions** ( $\text{SO}_4^{=}$ ,  $\text{NO}_3^-$ ,  $\text{NH}_4^+$ ,  $\text{Na}^+$ ,  $\text{Cl}^-$ ) + OC + EC + **trace elements**

bulk chemical composition is the most reliable technique for quantifying the concentration of dust and other species (if present, e.g. pollutants, sea salt).

**This is considered a reference method for the quantification of dust.**

Other analytical techniques are available. Scanning Electron Microscopy (SEM) and Transmission Electron Microscopy (TEM) coupled with Energy Dispersive X-ray analysis (EDX) allows individual particle characterization for size, morphology, chemical and mineral composition.



-  at least 4 years
-  Active during the last 20 years

Review Article

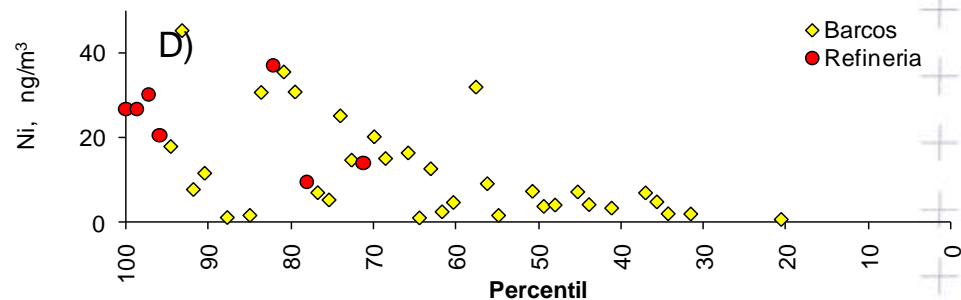
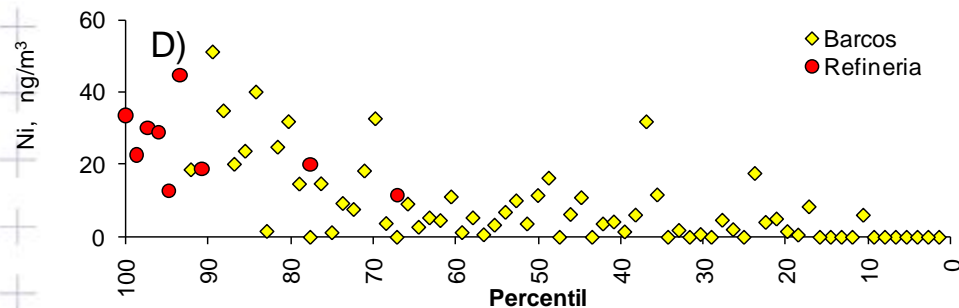
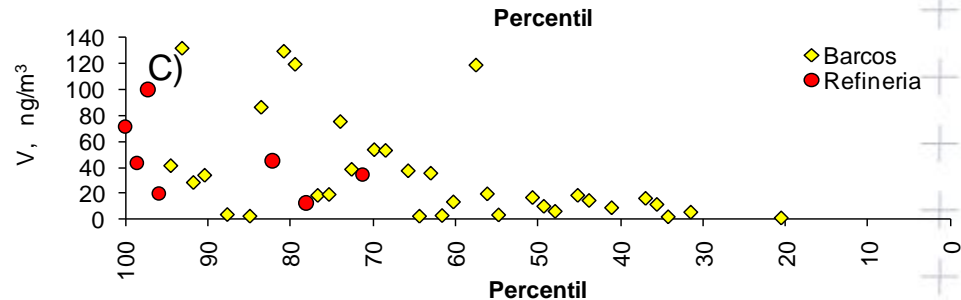
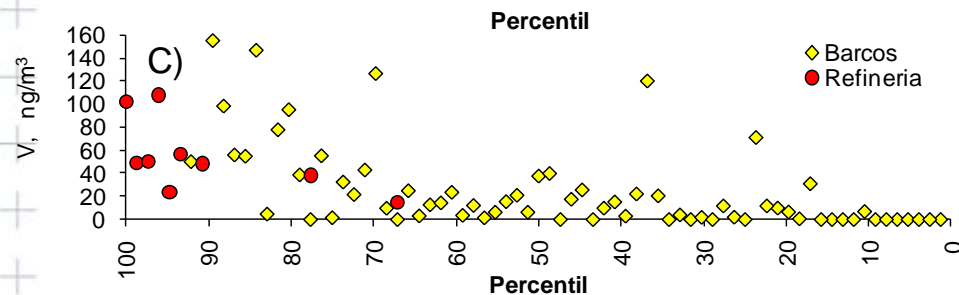
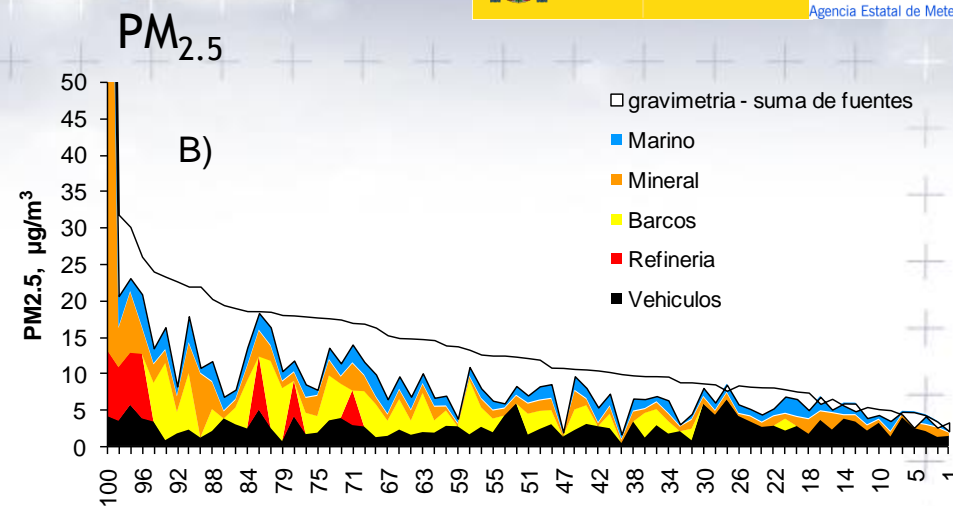
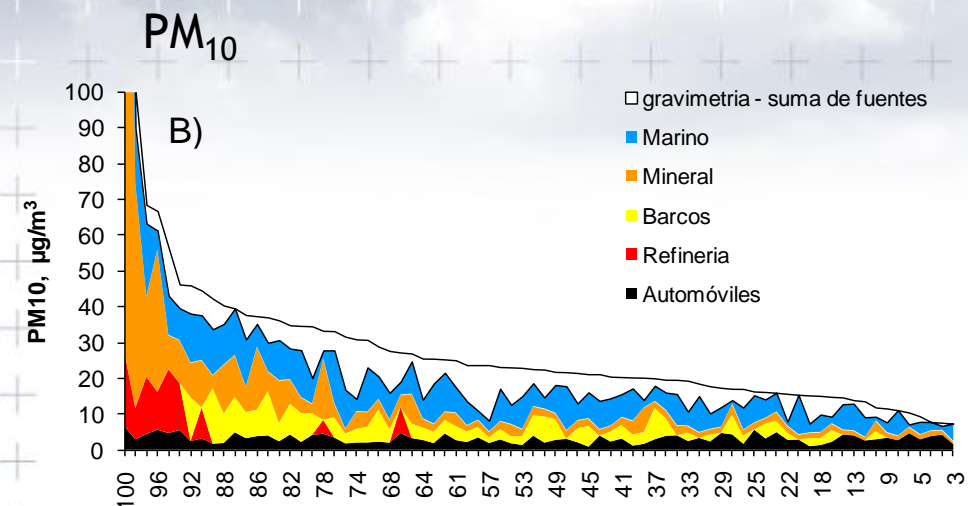
**Aeolian Research** Aeolian Research 6 (2012) 55–74

A review of methods for long term in situ characterization of aerosol dust

Sergio Rodríguez<sup>a,\*</sup>, Andrés Alastuey<sup>b</sup>, Xavier Querol<sup>b</sup>

bulk chemical composition reference method for the quantification of dust.





Santa Cruz de Tenerife source apportionment study by receptor modeling  
*Rodríguez et al., 2009*



## property of aerosol dust:

number size distribution

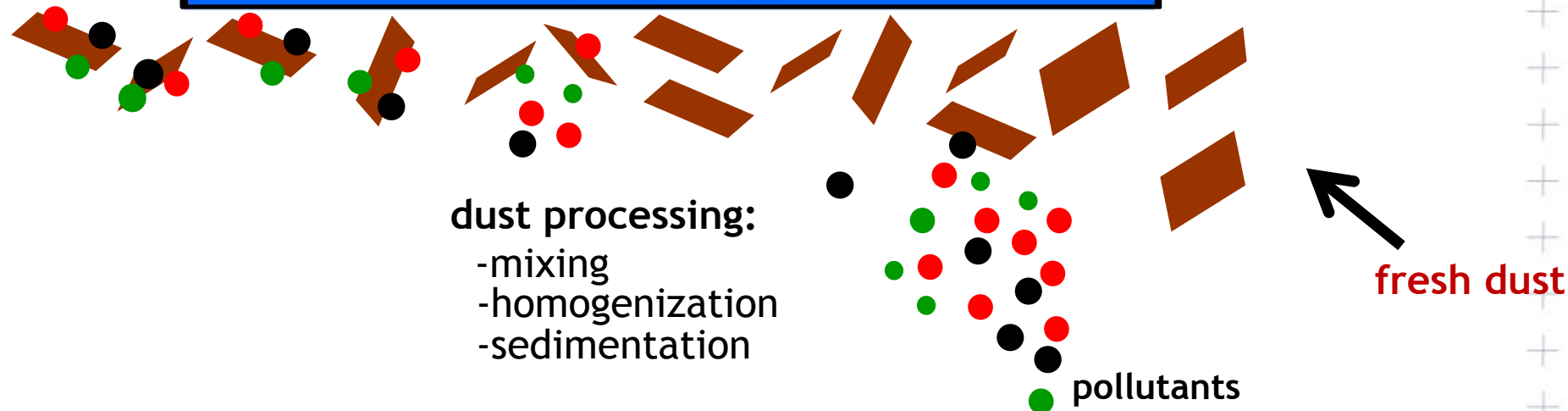
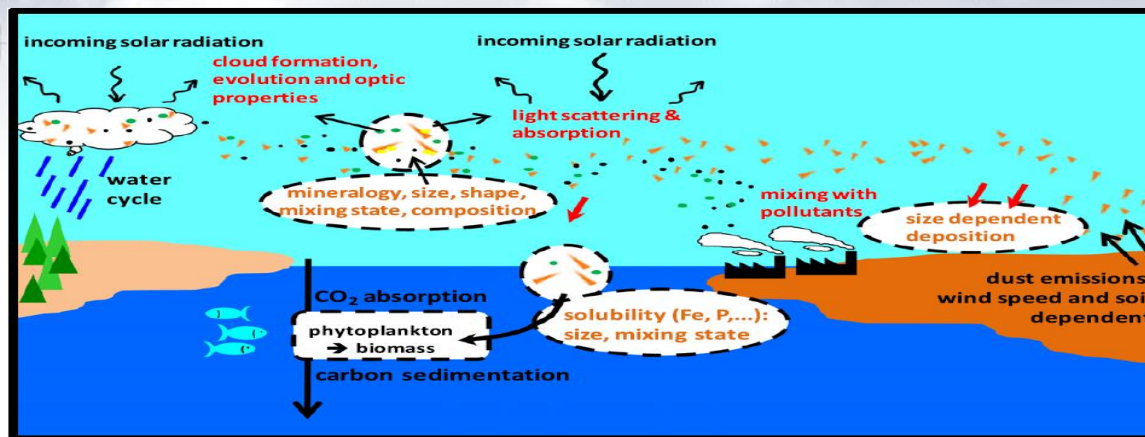
mass concentration

chemical composition

**mixing state**

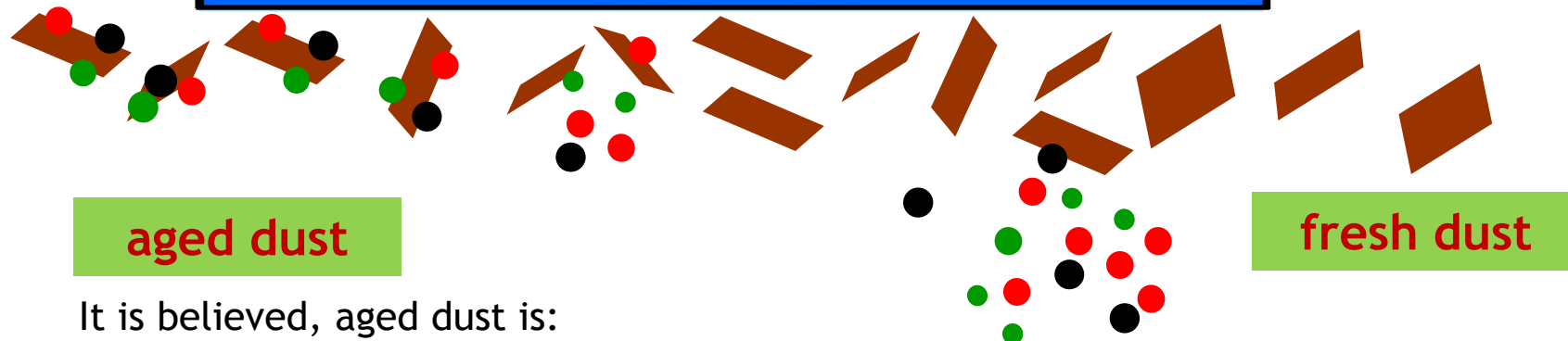
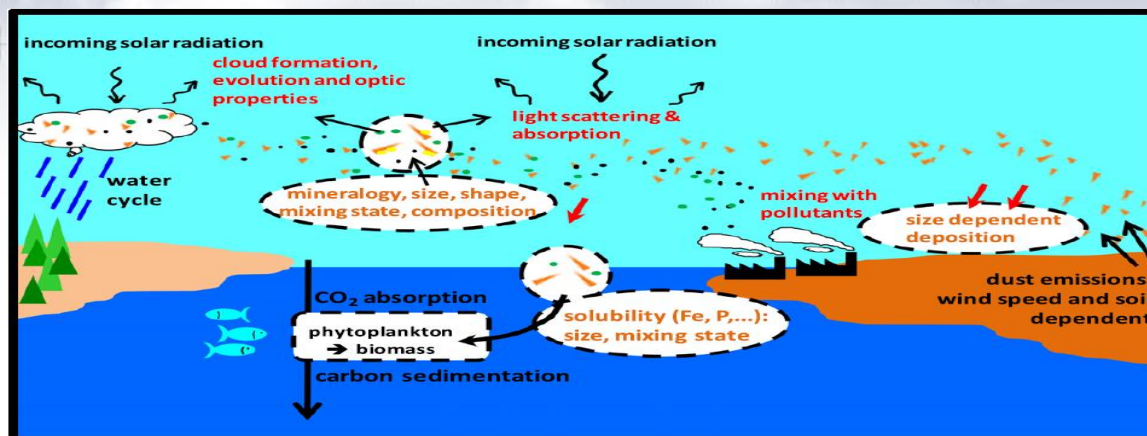
mineralogy

optical properties



**internal mixing:**  
all particles the same composition  
(same mixing)

**external mixing:**  
each particle different chemical composition

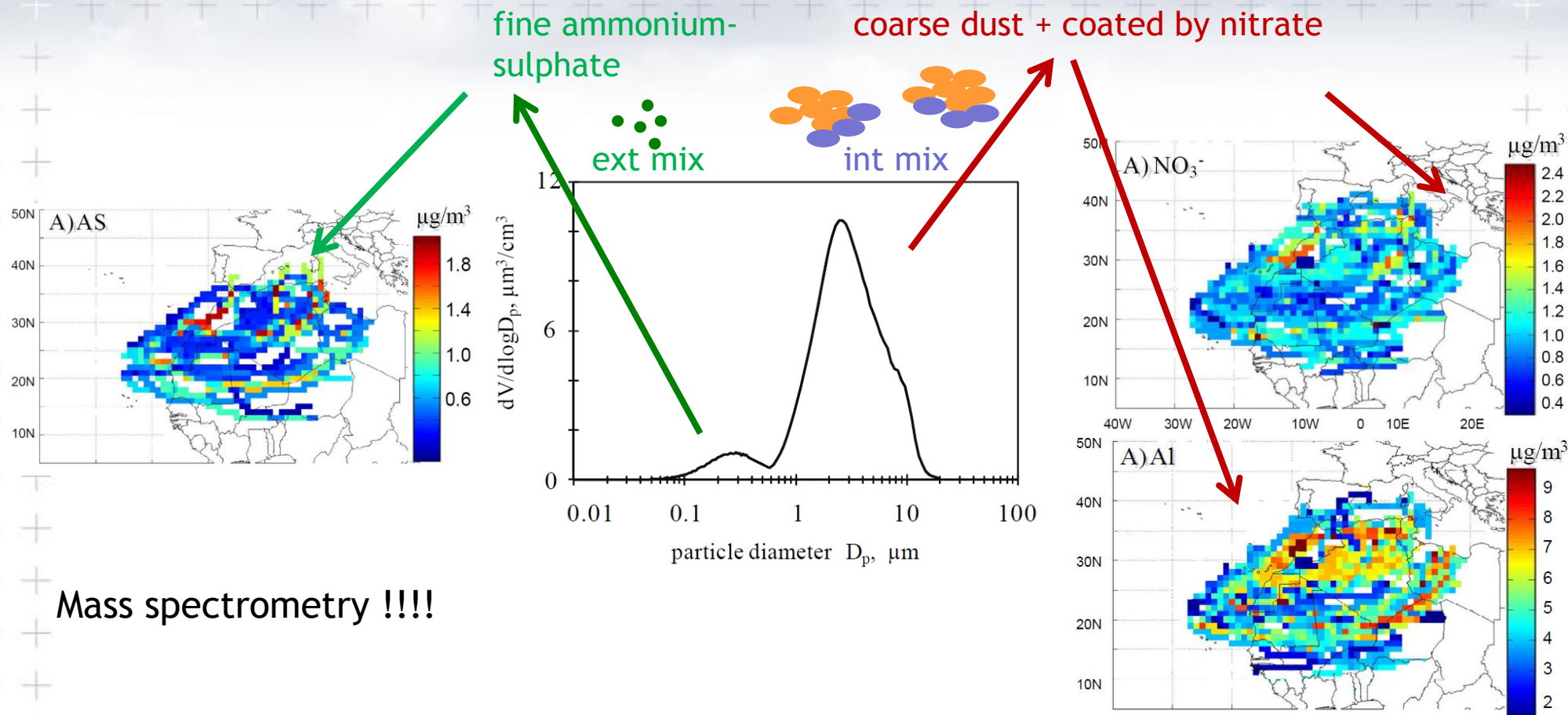


**aged dust**

**fresh dust**

It is believed, aged dust is:

- more soluble
- different refractive index



Mass spectrometry !!!!

## Transport of desert dust mixed with North African industrial pollutants in the subtropical Saharan Air Layer

S. Rodríguez<sup>1</sup>, A. Alastuey<sup>2</sup>, S. Alonso-Pérez<sup>1,2</sup>, X. Querol<sup>2</sup>, E. Cuevas<sup>1</sup>, J. Abreu-Afonso<sup>1</sup>, M. Viana<sup>2</sup>, N. Pérez<sup>2</sup>, M. Pandolfi<sup>2</sup>, and J. de la Rosa<sup>3</sup>

Atmos. Chem. Phys., 11, 6663–6685, 2011

[www.atmos-chem-phys.net/11/6663/2011/](http://www.atmos-chem-phys.net/11/6663/2011/)

doi:10.5194/acp-11-6663-2011

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Atmospheric Environment 44 (2010) 3135–3146

Variation of the mixing state of Saharan dust particles with atmospheric transport

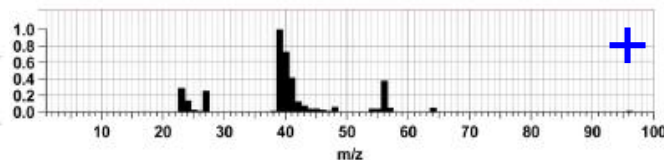
Manuel Dall'Osto<sup>a,b</sup>, Roy M. Harrison<sup>a,\*</sup>, Eleanor J. Highwood<sup>c</sup>, Colin O'Dowd<sup>b</sup>, Darius Ceburnis<sup>b</sup>,  
Xavier Querol<sup>d</sup>, Eric P. Achterberg<sup>e</sup>

Aerosol Time Of Flight Mass Spectrometer (ATOFMS)

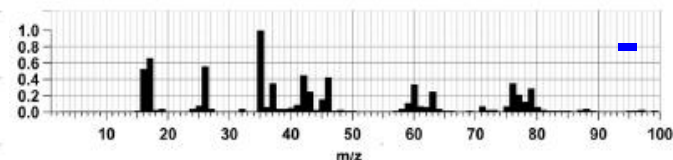
-aerodynamic size of particles (0.3 - 1  $\mu\text{m}$ )

-chemical composition of individual particles

→ positive and negative ion mass spectrums of a single particle.



m/z: 27 (Al), 40 and 56 (Ca).....



m/z: -97 ( $\text{HSO}_4^-$ ), -80 ( $\text{SO}_3^-$ ), -62 ( $\text{NO}_3^-$ ).....

The mass spectrum is qualitative in that the intensities of the mass spectral peaks are not directly proportional to the component mass but are dependent on the particle matrix.

Not for long term measurements

The ATOFMS can supply quantitative information on particle number as a function of composition, providing measurements of all the particle components (including OC, EC, sulfate, nitrate, dust and sea salt)



## property of aerosol dust:

number size distribution

mass concentration

chemical composition

mixing state

mineralogy

**optical properties**

## optical properties

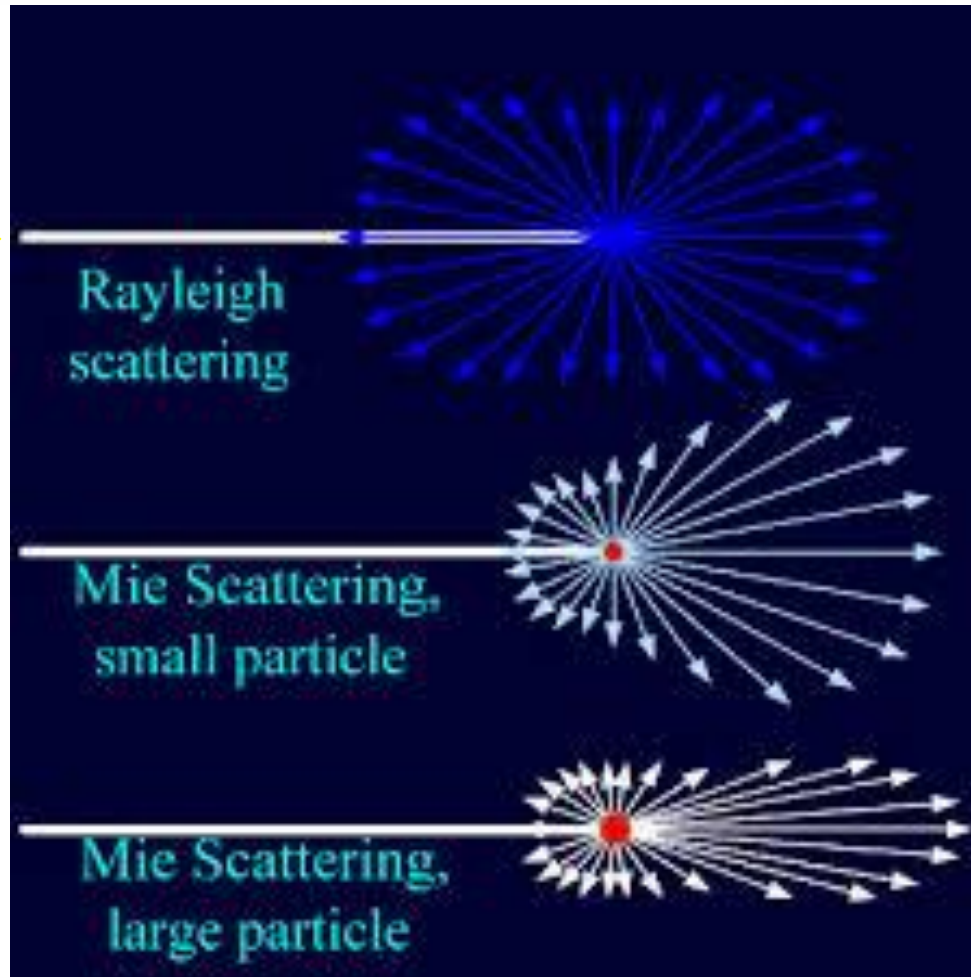
### Redistribution of radiation depends on:

-particle size

forward scattering increase with  
particle size

-composition and mineralogy

mixing with pollutants  
absorbing minerals (iron oxides)



$$\lambda > r$$

$$\lambda \sim r$$

$$\lambda \ll r$$

## optical properties

scattering and backscattering coefficient (several  $\lambda$ )

2 basic optical properties:

absorption coefficient (several  $\lambda$ )

$$I = I_0 \cdot e^{-\sigma_{\text{ext}} \cdot L}$$

$$\sigma_{\text{ext}} = \sigma_{\text{abs}} + \sigma_{\text{scat}}$$

Measured in Inverse Meters ( $\text{m}^{-1}$ )  
“How Much is Extinguished Per Meter?”

$\sigma_{\text{ext}}$  aerosol extinction coefficient

$\sigma_{\text{abs}}$  aerosol absorption coefficient : Absorption Photometer  
(MAAP, Aethalometer, PSAP)

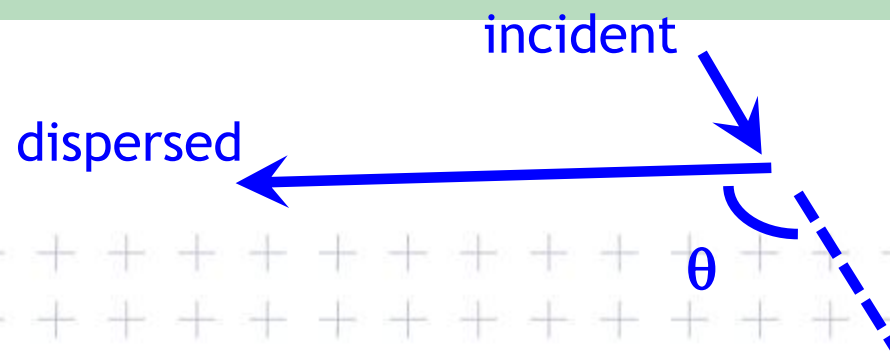
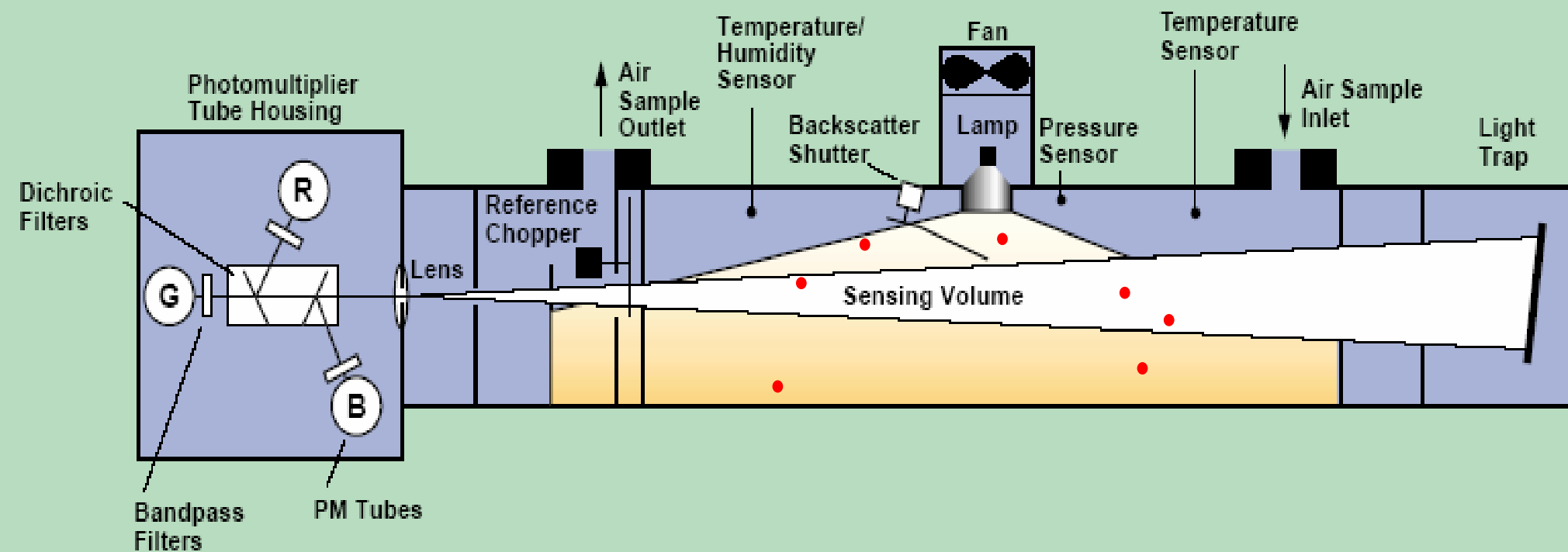
$\sigma_{\text{scat}}$  aerosol scattering coefficient: **NEPHELOMETER**

2 basic optical properties:

scattering ( $\sigma_{\text{scat}}$ ) and backscattering coefficient (several  $\lambda$ )

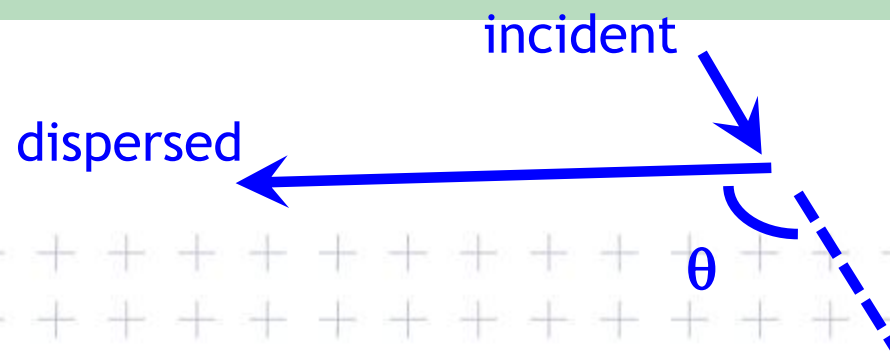
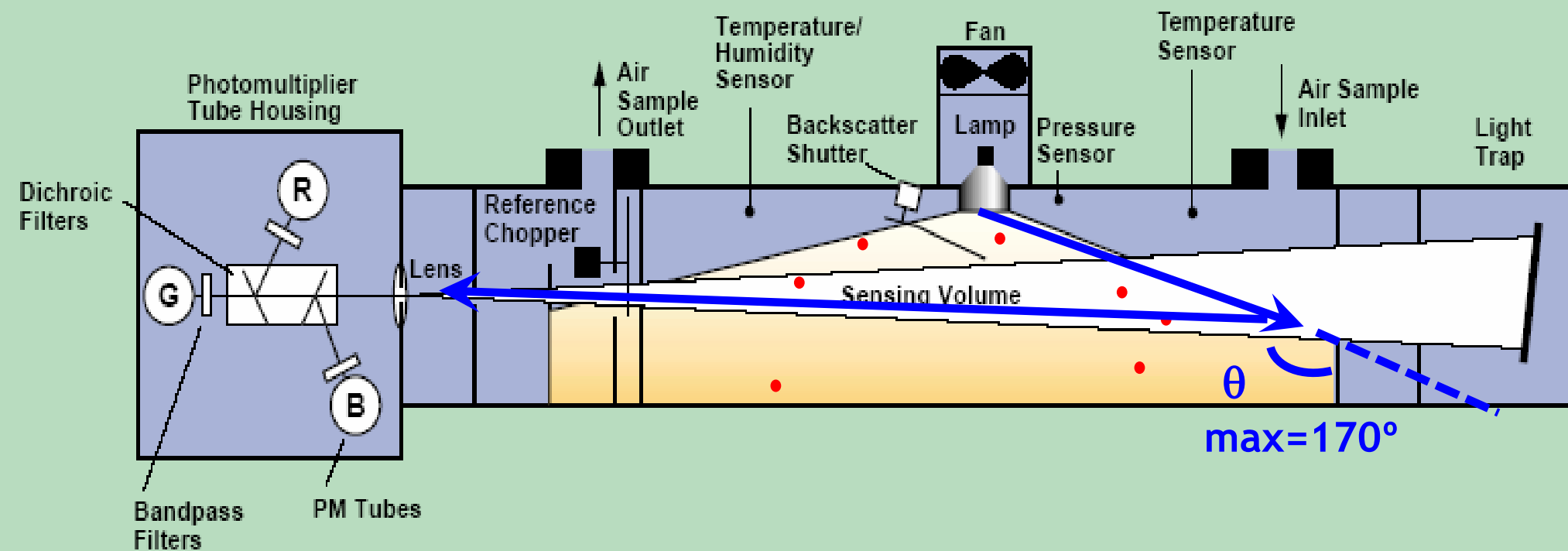
absorption coefficient (several  $\lambda$ )

## Integrating Nephelometer **coeficiente de scattering**

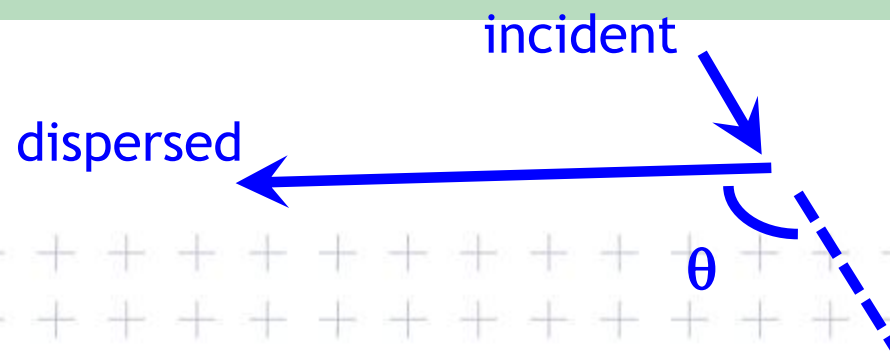
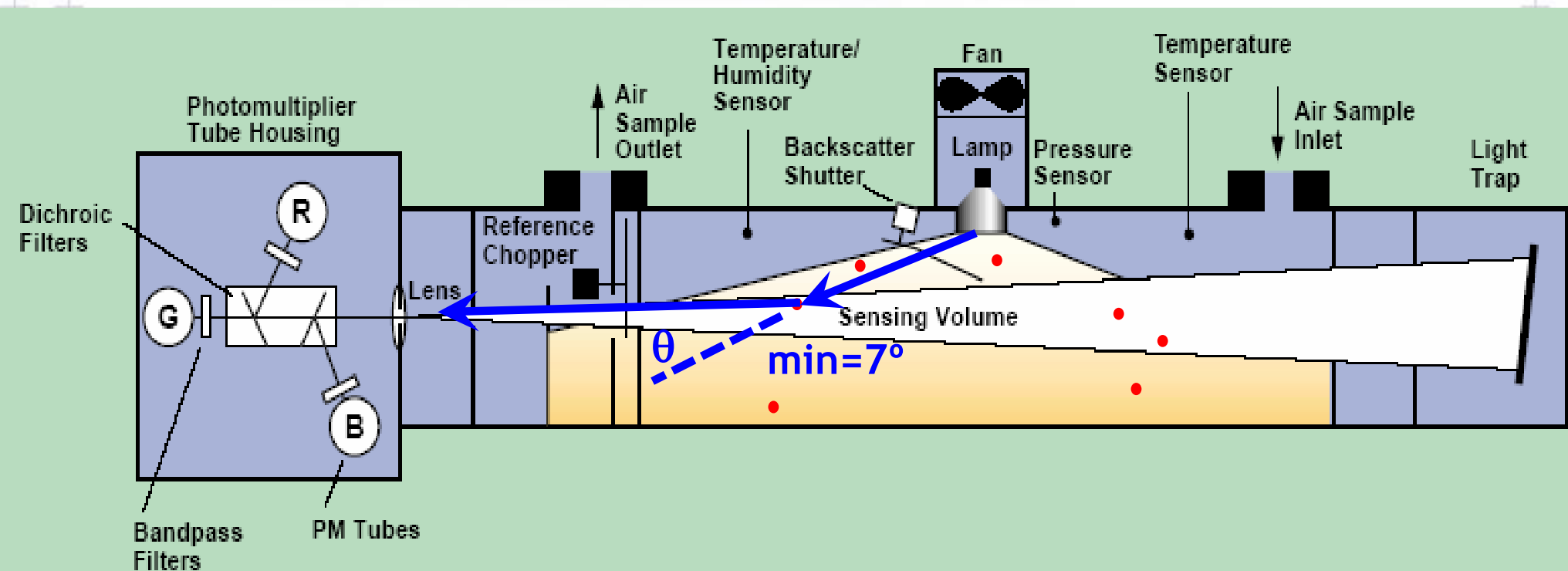




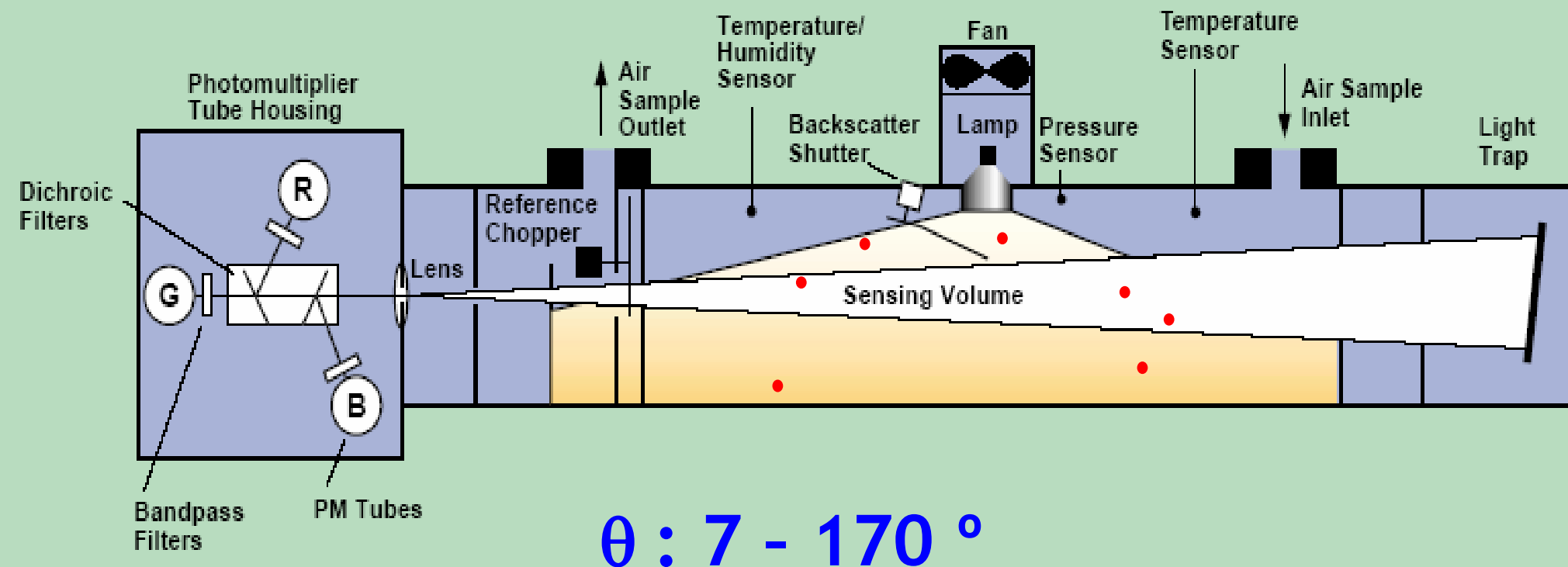
## Integrating Nephelometer Scattering coefficient



## Integrating Nephelometer **Scattering coefficient**



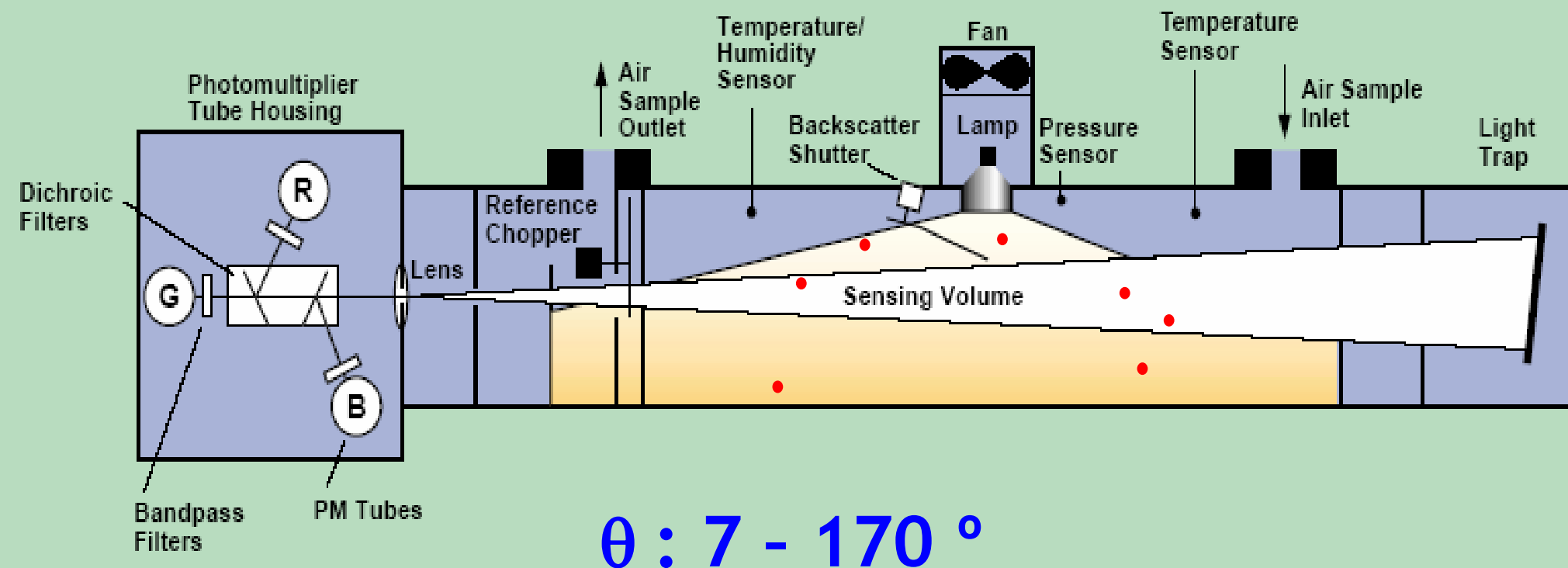
## Integrating Nephelometer **Scattering coefficient**



## Integrating nephelometer

**Scattering Coefficient 7 - 170 °**

## Integrating Nephelometer **Scattering coefficient**



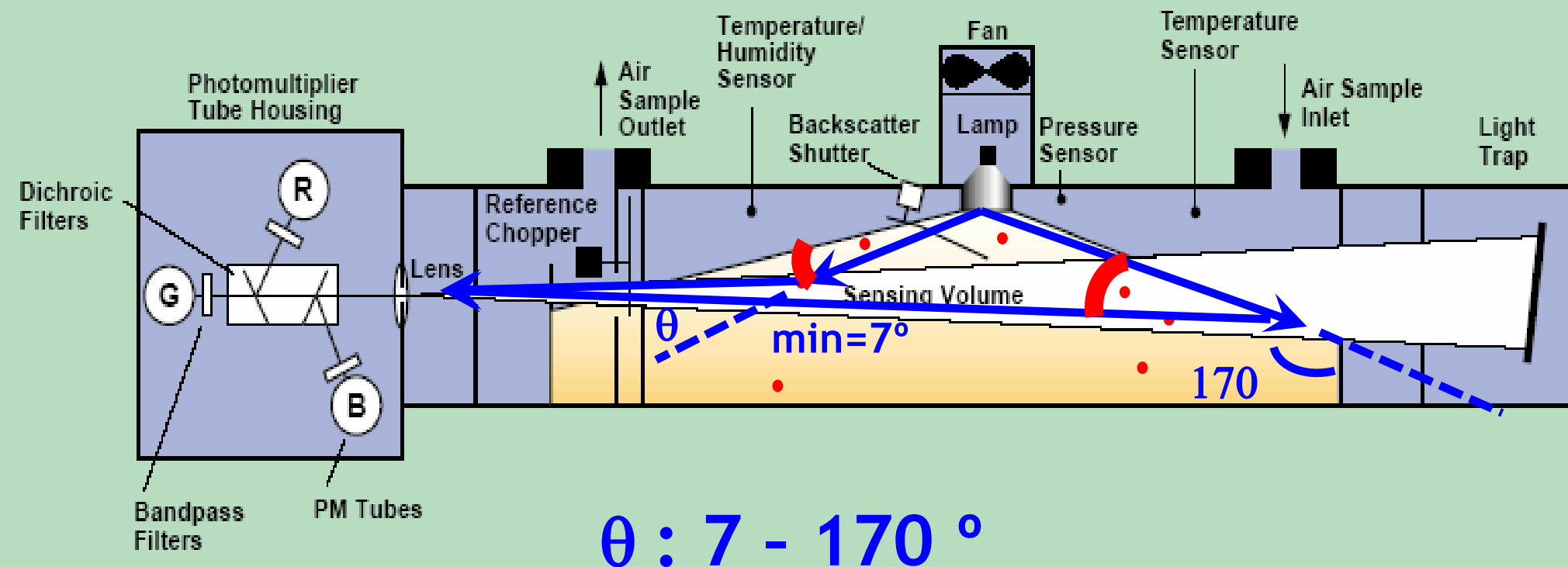
## Integrating nephelometer

Total Scattering coefficient  $7 - 170^\circ$

Total Backscattering coefficient  $90 - 170^\circ$

$\lambda = 450, 550, 700 \text{ nm}$

## Integrating Nephelometer: Truncation correction



Total scattering coefficient  $7 - 170^\circ$

Truncation error: light dispersed within the angles  $0-7^\circ$  and  $170-180^\circ$  is not measured



Forward scattering increase with particle size.

Coarse dust particles → TRUNCATION ERROR

TRUNCATION CORRECTION IS IMPORTANT FOR DUST

Correction scheme → Anderson y Ogren (1998).

Anderson, T.L., Ogren, J.A., 1998. Determining aerosol radiative properties using the TSI 3563 Integrating Nephelometer. Aerosol Science and Technology, 29, 57-69.

$$C = \frac{\sigma_{\text{true}}}{\sigma_{\text{neph}}},$$

$$C = a + b \cdot \tilde{A}^b$$

$$\tilde{A}(\lambda_1/\lambda_2) = - \frac{\log(\sigma_{\text{sp}}^{\lambda_1}/\sigma_{\text{sp}}^{\lambda_2})}{\log(\lambda_1/\lambda_2)}.$$

Ångstrom exponent

Ångstrom exponent

high values (e.g. > 0.7) fine particles

high values (e.g. < 0.7) coarse particles, DUST

b) Correction factors for total scatter as a linear function of Ångström exponent using  $C = a + b \cdot \tilde{A}^b$

	450 nm				550 nm				700 nm			
	a	b	residual		a	b	residual		a	b	residual	
			mean	max			mean	max			mean	max
No cut	1.365	-.156	0.050	0.22	1.337	-.138	0.046	0.21	1.297	-.113	0.042	0.17
Sub- $\mu\text{m}$	1.165	-.046	0.010	0.031	1.152	-.044	0.007	0.022	1.120	-.035	0.004	0.014

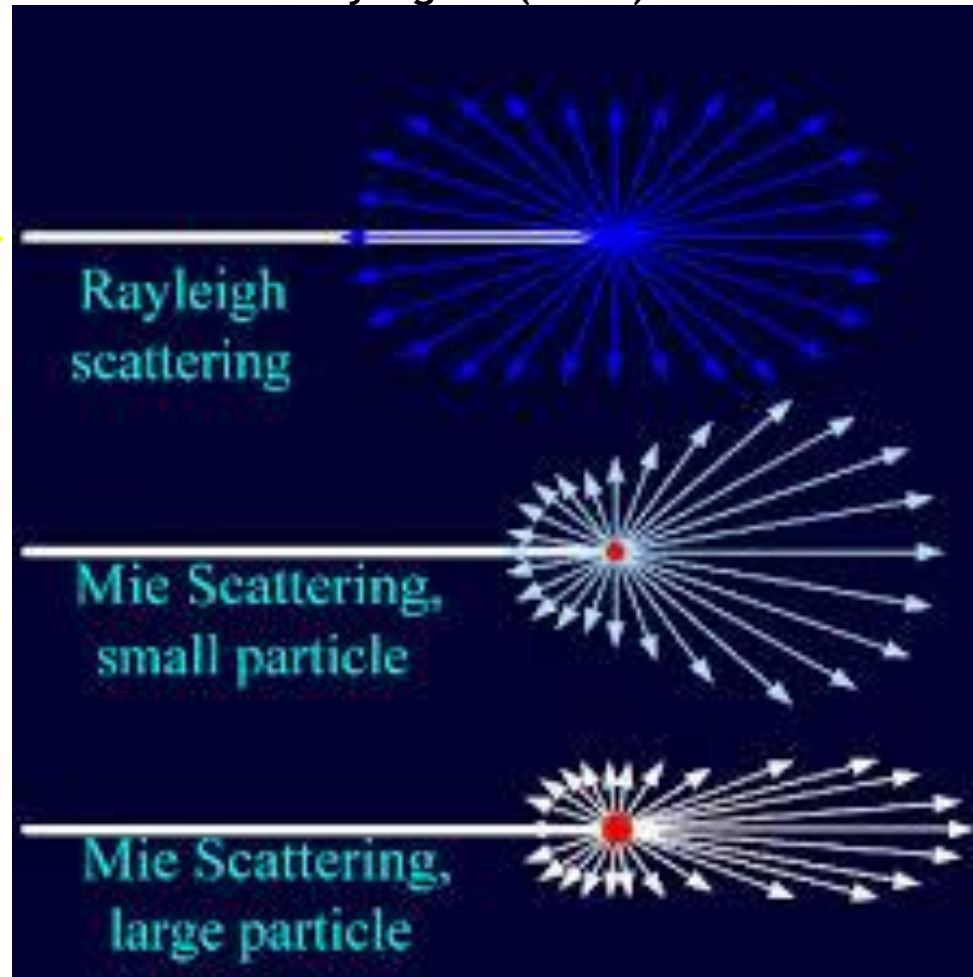
<sup>a</sup> Bimodal, lognormal size distributions with ranges of volume mean diameters and refractive indices given in text. The range of fine mode mass fraction is 0.9 to 0.1.

<sup>b</sup>  $\tilde{A}$ -values for input to this formula are calculated from Eq. (11) using uncorrected nephelometer measurements of  $\sigma_{\text{sp}}$  at two wavelengths;  $\tilde{A}(450/550)$  at 450 nm,  $\tilde{A}(450/700)$  at 550 nm, and  $\tilde{A}(550/700)$  at 700 nm.

If correction is not applied, the total scattering is underestimated by between 5-15% for submicron particles and by 40-60% for coarse particles

Forward scattering increase with particle size.  
Coarse dust particles → TRUNCATION ERROR  
TRUNCATION CORRECTION IS IMPORTANT FOR DUST  
Correction scheme → Anderson y Ogren (1998).

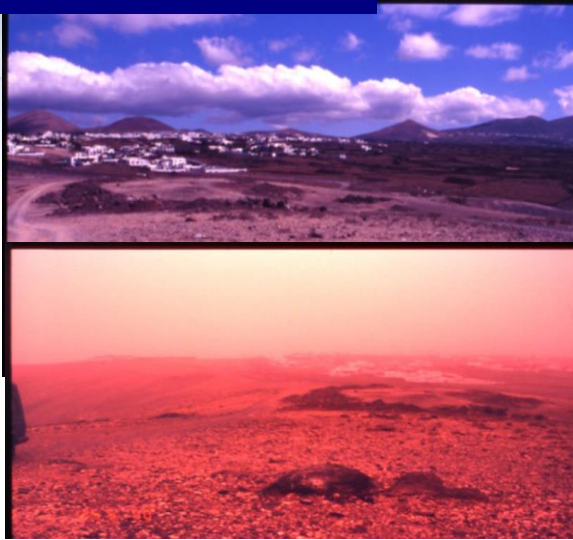
If correction is not applied, the total scattering is underestimated by between 5-15% for submicron particles and by 40-60% for coarse particles



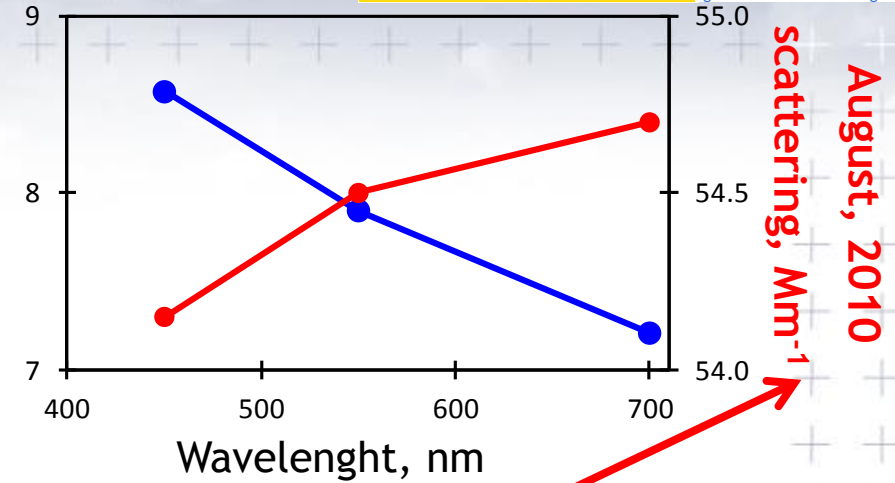
Back scattering

Forward scattering

# In-situ dust characterization

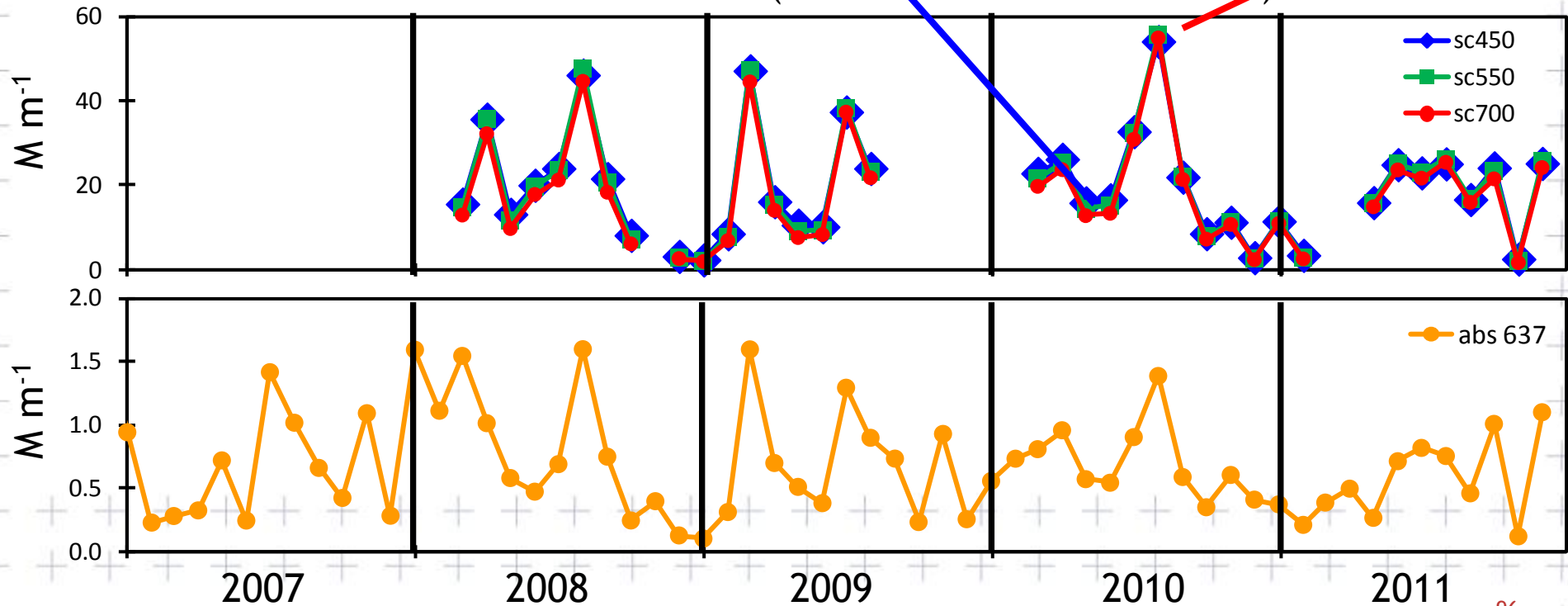


March, 2010  
scattering,  $\text{Mm}^{-1}$



Optical properties: scattering and absorption

(note that  $1 \text{ Mm}^{-1} = 10^{-6} \text{ m}^{-1}$ )



## optical properties

scattering ( $\sigma_{sp}$ ) and backscattering coefficient (several  $\lambda$ )

2 basic optical properties:

absorption coefficient (several  $\lambda$ )

MAAP: Multi-Angle

Absorption Photometer

PSAP: Particle Soot

Absorption Photometer

3 $\lambda$

Aethalometer

5–7  $\lambda$



$\lambda=670\text{nm}$



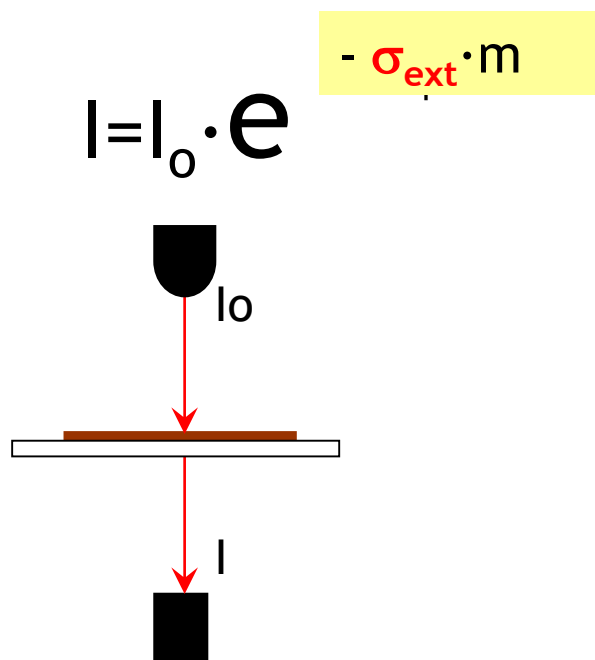


## optical properties

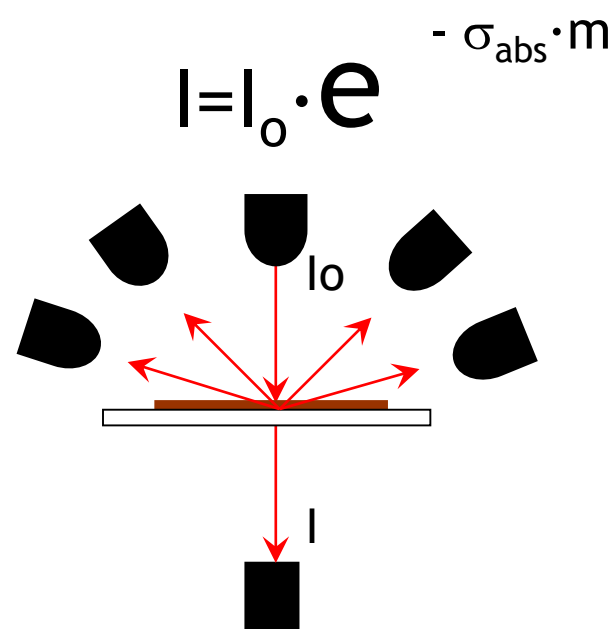
scattering ( $\sigma_{\text{scar}}$ ) and backscattering coefficient (several  $\lambda$ )

2 basic optical properties:

absorption coefficient (several  $\lambda$ )



Aethalometer and PSAP

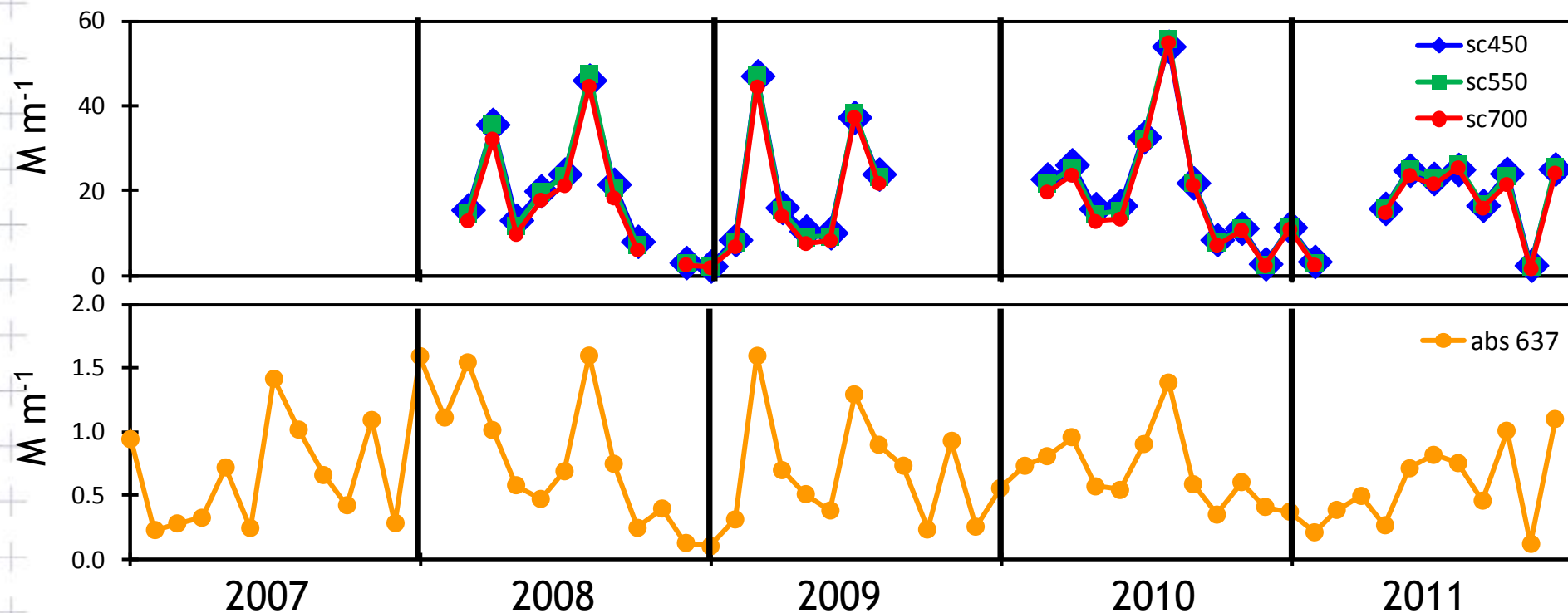


MAAP: MultiAngle Absorption Photometer

Abs. Coeff. (aethalometer and PSAP) > Abs. Coeff. (MAAP)



Long term monitoring of optical properties with simultaneous chemical and mineralogical characterization allows to understand potential changes in the optical properties due to changes in the dust and pollutants mixing or changes in the dust-sources



## property of aerosol dust:

number size distribution

mass concentration

chemical composition

mixing state

**mineralogy**

optical properties

## Dust is a mixing of different minerals:

type	common name	uma--> formula empirica
clay	Montmorillonite	$\text{Na}_{0.2}\text{Ca}_{0.1}\text{Al}_2\text{Si}_4\text{O}_{10}(\text{OH})_2(\text{H}_2\text{O})_{10} \cdot n(\text{H}_2\text{O})$
clay	Smectite	$(\text{Na}, \text{Ca})\text{Al}_4(\text{Si}, \text{Al})_8\text{O}_{20}(\text{OH})_4 \cdot 2(\text{H}_2\text{O})$
clay	Chlorite	$\text{Na}_{0.5}(\text{Al}, \text{Mg})_6(\text{Si}, \text{Al})_8\text{O}_{18}(\text{OH})_{12} \cdot 5(\text{H}_2\text{O})$
Ca rich	calcite	$\text{CaCO}_3$
Ca rich	dolomite	$\text{CaMg}(\text{CO}_3)_2$
Ca rich	gypsum	$\text{CaSO}_4 \cdot 2(\text{H}_2\text{O})$
Ca rich	anhydrite	$\text{CaSO}_4$
SiO <sub>2</sub>	quartz	$\text{SiO}_2$
Feldspars	mocridine	$\text{KAlSi}_3\text{O}_8$
Plagioclase feldspar	Var oligoclase	$(\text{Na}, \text{Ca})[\text{Si}, \text{Al}]_4\text{O}_8$
Plagioclase feldspar	Var albite	$\text{NaAlSi}_3\text{O}_8$
Plagioclase feldspar	Var anorthite	$\text{CaAl}_2\text{Si}_2\text{O}_8$
Oxides	hematite	$\text{Fe}_2\text{O}_3$
Oxides	goethite	$\text{FeO}(\text{OH})$
Oxides	gibbsite	$\text{Al}(\text{OH})_3$
Oxides	rutile	$\text{TiO}_2$
Salt	halite	$\text{NaCl}$

close chemical composition,  
but different mineralogy



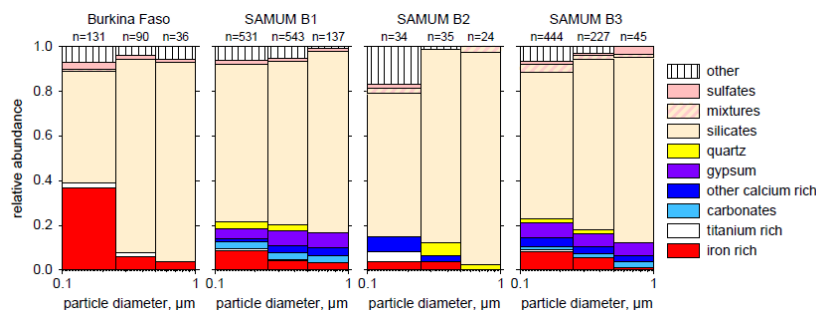
different optical properties

Dust is a mixing of different minerals:

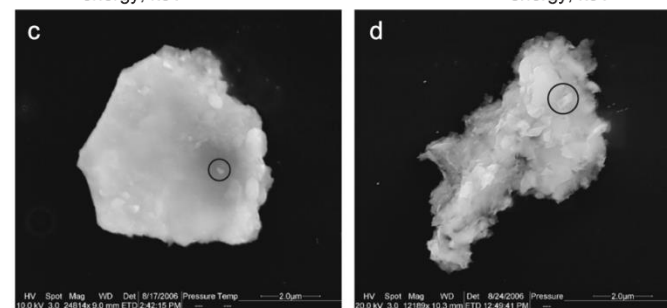
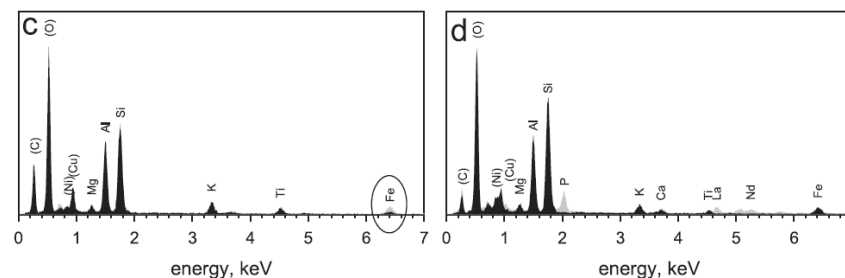
Techniques for the identification of different minerals:

- X-Ray diffraction
- Scanning Electron Microscopy (SEM) and Transmission Electron Microscopy (TEM) individual particle characterization for size, morphology, chemical and mineral composition.

not for long term monitoring



Component	Burkina Faso	SAMUM B1	SAMUM B3
"Quartz"	0.004	0.012	0.006
"Hematite"	0.027	0.016	0.011
"Calcite"	0.001	0.092	0.055
"Average Silicate"	0.949	0.842	0.867
"Sulphate"	0.019	0.037	0.061



Chemical composition and complex refractive index of Saharan Mineral Dust at Izaña, Tenerife (Spain) derived by electron microscopy

Konrad Kandler<sup>a,\*</sup>, Nathalie Benker<sup>a</sup>, Ulrich Bundke<sup>b</sup>, Emilio Cuevas<sup>c</sup>, Martin Ebert<sup>a</sup>, Peter Knippertz<sup>d</sup>, Sergio Rodriguez<sup>c,e</sup>, Lothar Schütz<sup>d</sup>, Stephan Weinbruch<sup>a</sup>

Atmospheric Environment 41 (2007) 8058–8074

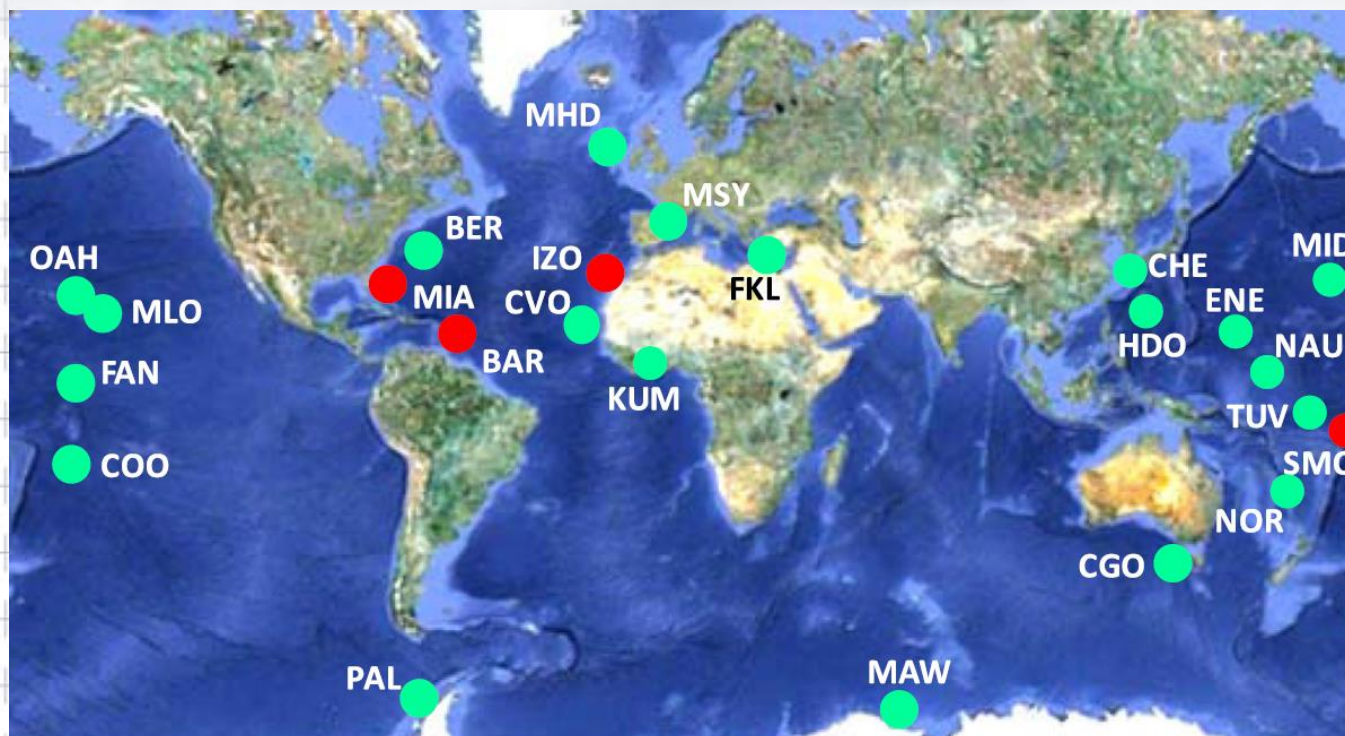
Complex refractive indices of Saharan dust samples

at visible and near UV wavelengths: a laboratory study

R. Wagner<sup>1</sup>, T. Ajtai<sup>2</sup>, K. Kandler<sup>3</sup>, K. Lieke<sup>3</sup>, C. Linke<sup>1</sup>, T. Müller<sup>4</sup>, M. Schnaiter<sup>1</sup>, and M. Vragel<sup>1</sup>

Atmos. Chem. Phys., 12, 2491–2512, 2012

## Long term monitoring dust background-observatories:



Review Article

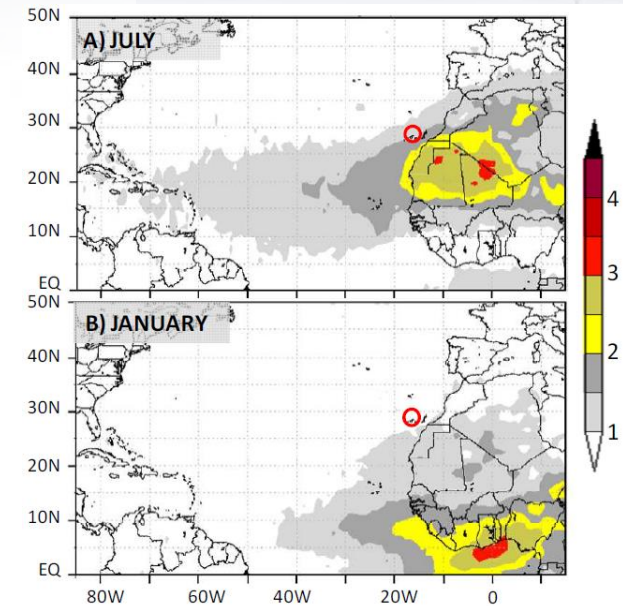
**Aeolian Research** Aeolian Research 6 (2012) 55–74

A review of methods for long term in situ characterization of aerosol dust

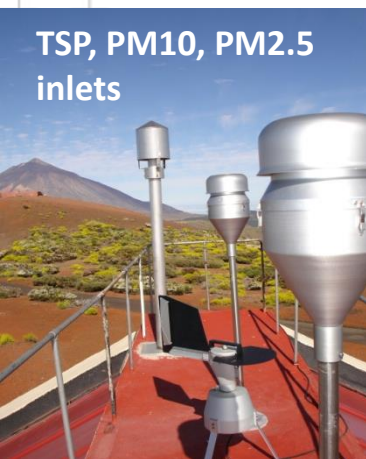
Sergio Rodríguez<sup>a,\*</sup>, Andrés Alastuey<sup>b</sup>, Xavier Querol<sup>b</sup>



Example of long term monitoring dust background-observatories, Izaña (Tenerife, The Canary Islands)



## In-situ aerosols GAW program:



Chemical composition, TSP: 1987, PM<sub>2.5</sub>: 2002, PM<sub>10</sub>: 2005 ...

Ultrafine particles (CPC 3025A): 1997 - 2009

Size distribution of fine and ultrafine particles (SMPS): 2008 - ...

Size distribution of coarse particles (APS): 2006 - ...

Scattering and backscattering (nephelometer): 2008 - ...

Absorption coefficient (1 λ): 2006 - ...

Absorption coefficient (7 λ): 2012 - ...



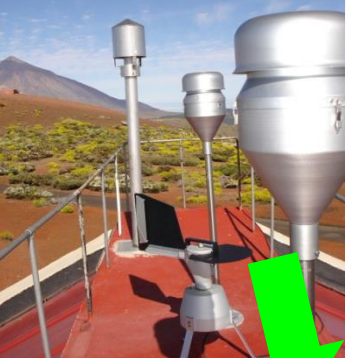
TSP, PM<sub>10</sub>, PM<sub>2.5</sub>  
inlets

Composición  
química

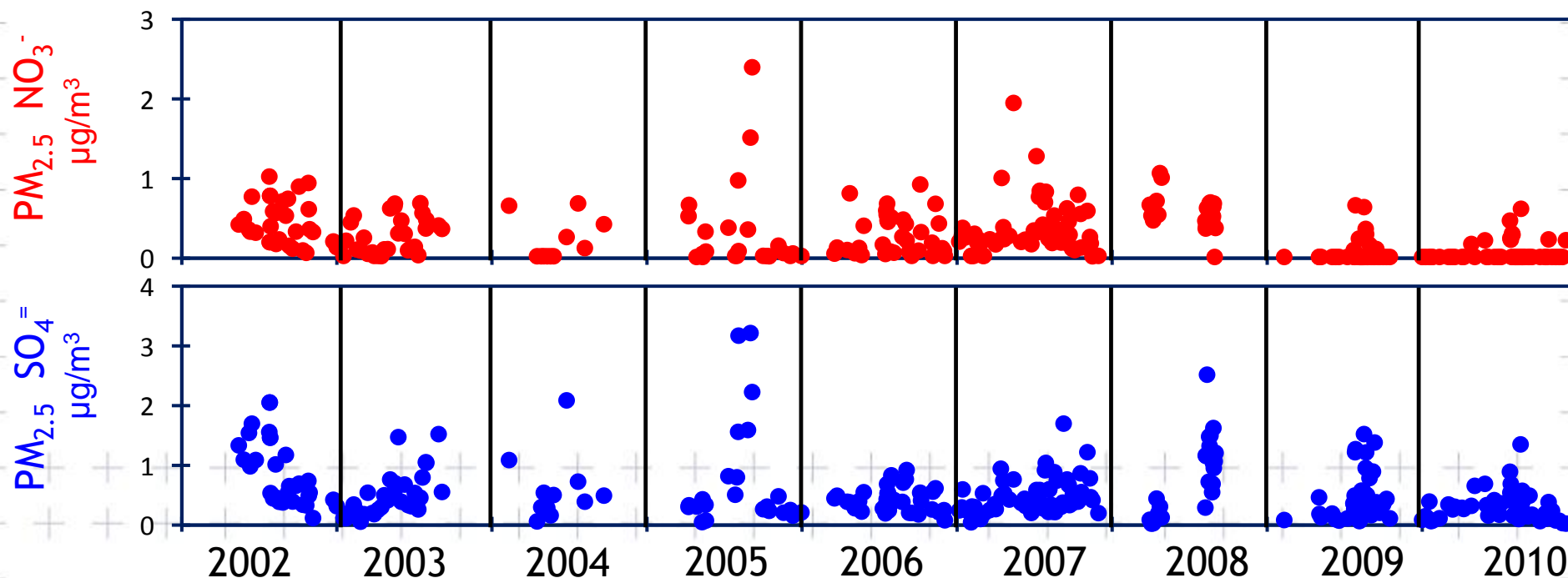
3λ scattering

absorción

Distribución tamaño  
APS+SMPS



Chemical composition (TSP, PM<sub>10</sub>, PM<sub>2.5</sub>): elemental (ICP-AES+ICP-MS) , ions (SO<sub>4</sub><sup>=</sup>, NO<sub>3</sub><sup>-</sup>, NH<sub>4</sub><sup>+</sup>), OC, EC



TSP, PM<sub>10</sub>, PM<sub>2.5</sub>  
inlets

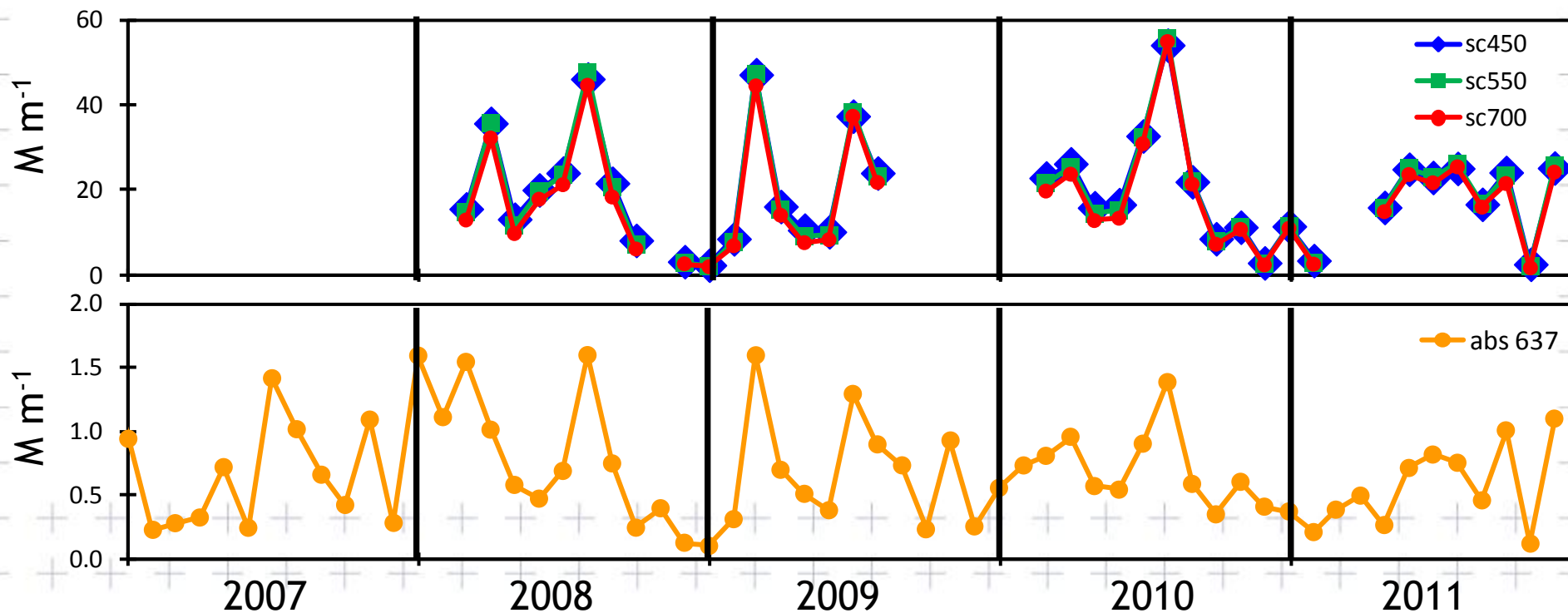
Composición  
química

3λ scattering

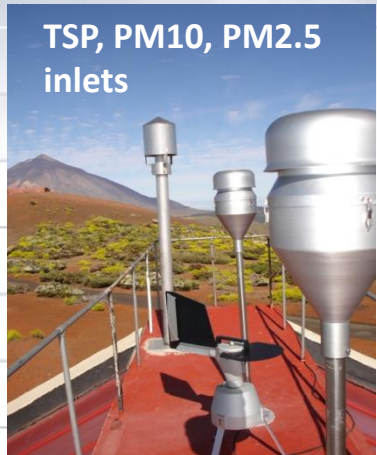
absorción

Distribución tamaño  
APS+SMPS

Optical properties: scattering and absorption



TSP, PM10, PM2.5 inlets



Composición química



$3\lambda$  scattering



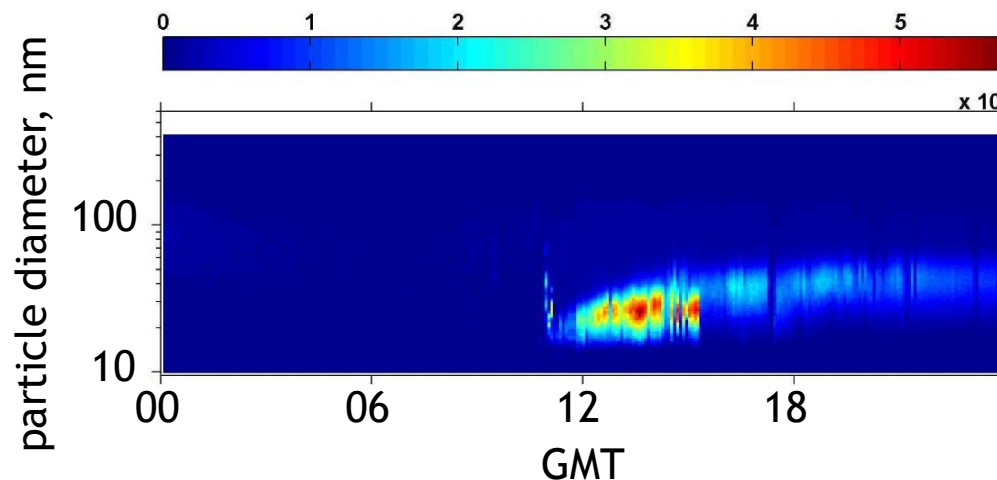
absorción



Distribución tamaño APS+SMPS



Size distribution: 10-500 nm (SMPS) + 0.5-20  $\mu\text{m}$  (APS)

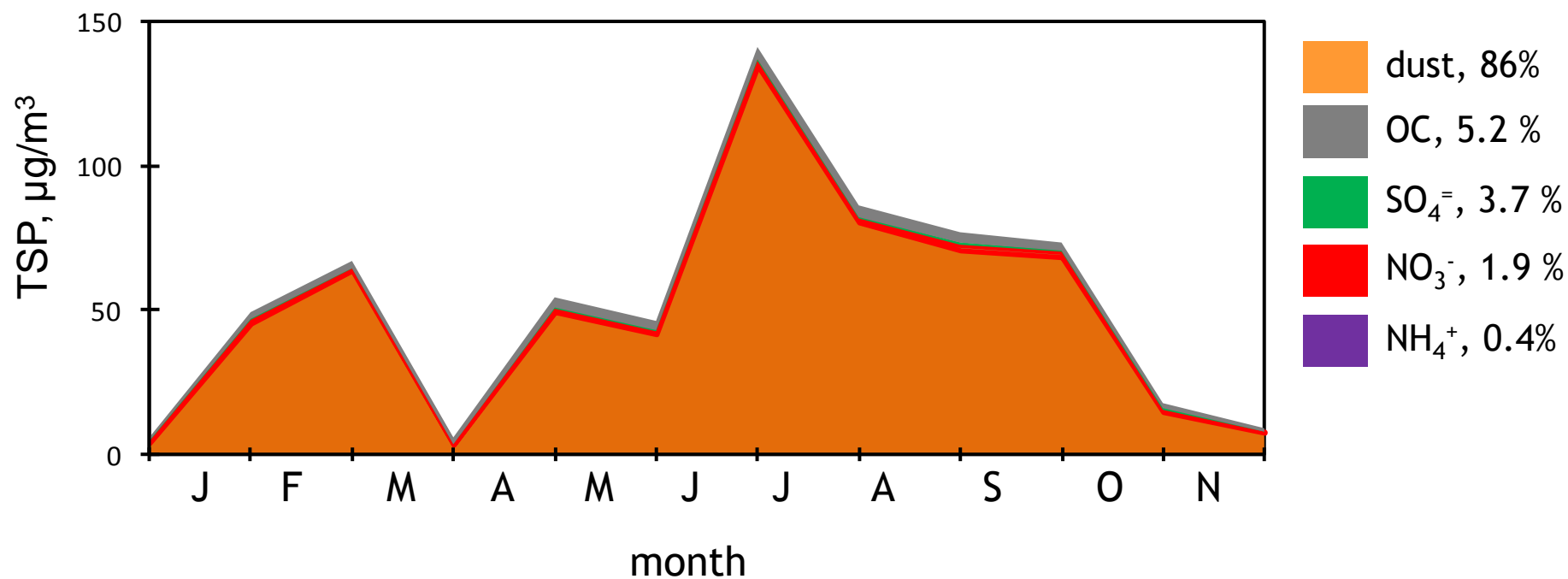


Example: new particle formation by nucleation

POLLUTANTS mixed with dust



Saharan dust is the most abundant aerosol we detect !!!!!



From ground observations...  
to ground estimations...

Visibility

# Index

- Aerosols and dust background
- In-situ dust characterization
- In-situ dust estimations (Visibility)
- Ground based remote sensing
- Summary

## WMO - visibility

The greatest distance that a black object of “suitable dimensions,” situated near the ground, can be seen and recognized when observed against a background of fog

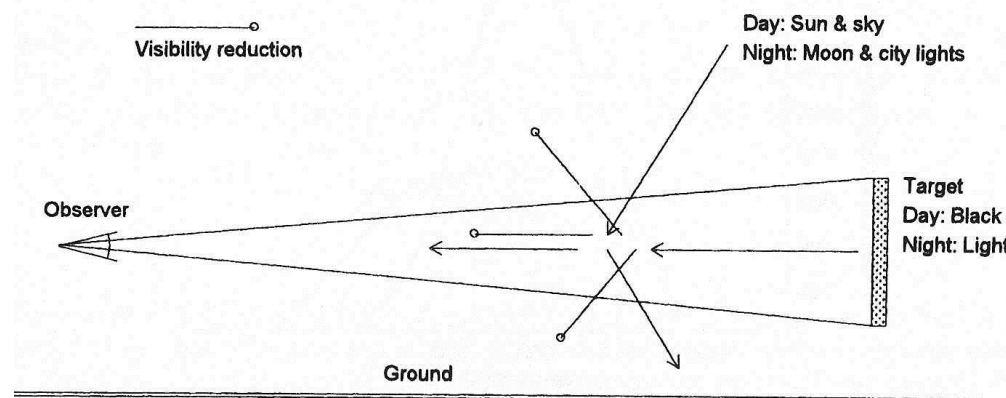


Fig. 11-1 Visibility reduction by scattering.

## aerosols are the main cause of visibility reduction

- Operational surface synoptic weather station reports from Global Telecommunication System (GTS)
- Station reports include past & present weather, visibility (km), temperature (°C), dew point temperature, wind direction (°), and speed (knots)

62733	15.32	35.60	02040818	Dust, not at time of obs.	6	0	18	22	320	2	35.5
62733	15.32	35.60	02041015	Dust, raised at time of obs.	7	0	99.	30	320	6	34.5
62733	15.32	35.60	02041121		-9	-9	-9	20	23	320	2 26.0
62733	15.32	35.60	02041212		-9	-9	-9	20	34	340	3 37.5

## Measurement of visibility - transmissometer & scatemeter

- A light source with one or two light detectors at fixed distances from the source
- Detectors are designed to receive light only from the source direction
- Often located along and parallel to a runway (runway visual range; RVR)

### transmissometer

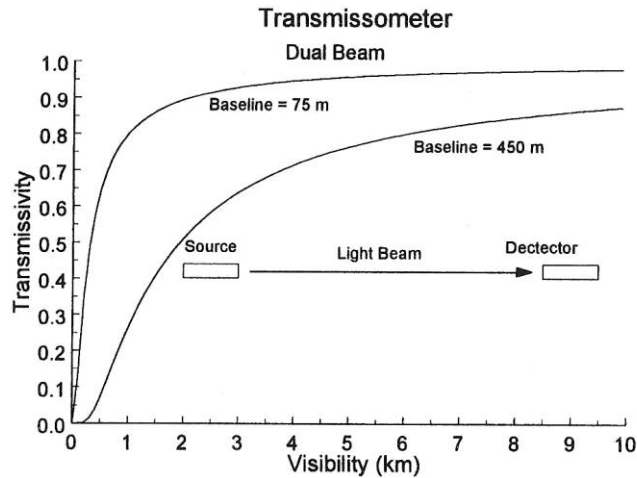


Fig. 11-3 Transfer function for a transmissometer.



### scatemeter

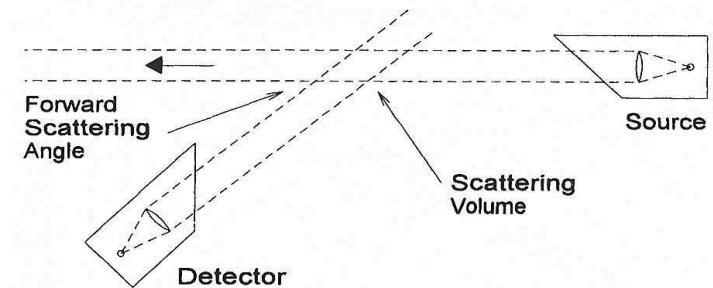
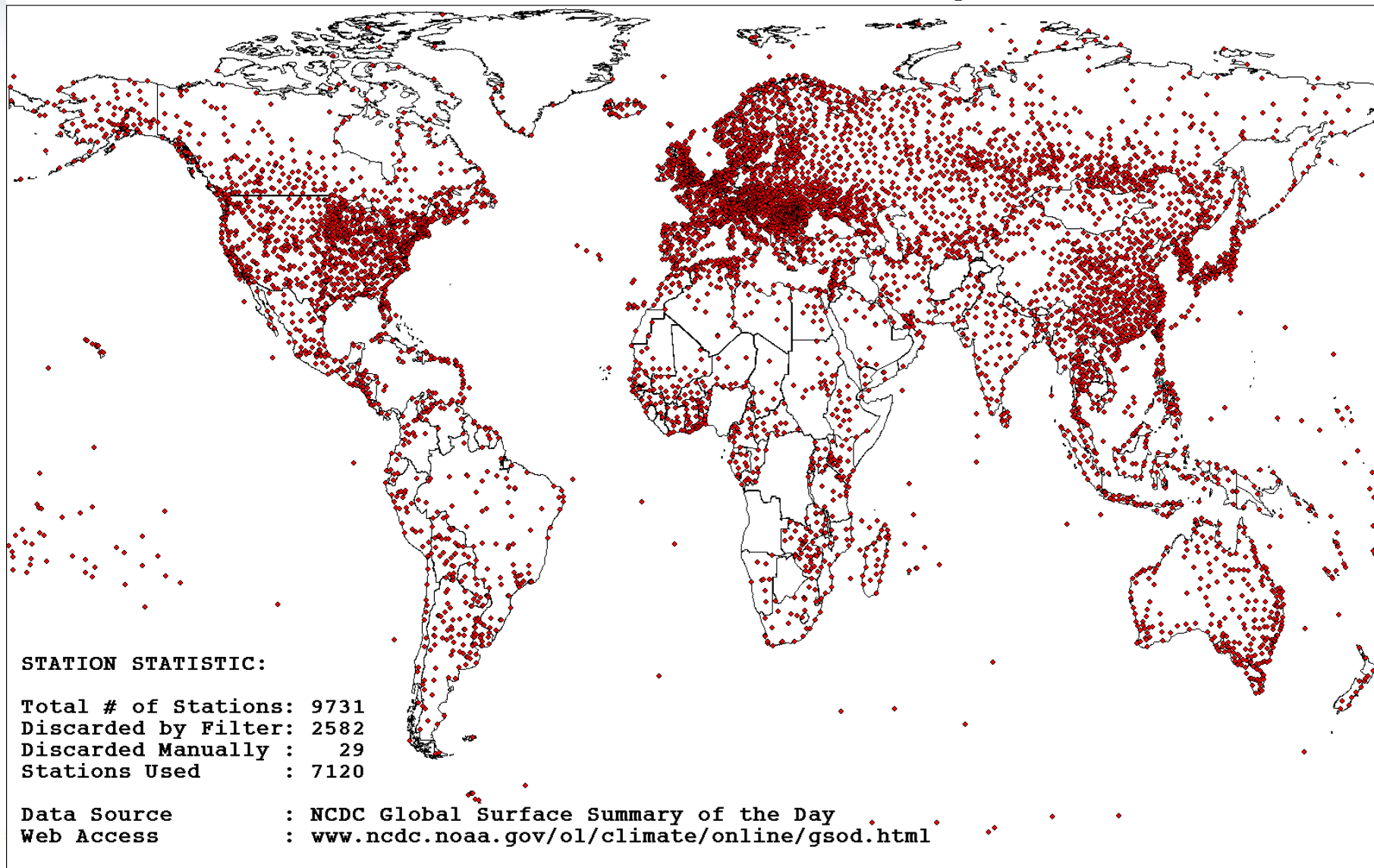


Fig. 11-4 A forward scatter visibility meter.

$$\text{Visual range (km)} = 3.912 / \sigma_{\text{ext}} \text{ (Mm}^{-1}\text{)}$$



## WMO- World Wide Watch Global Surface Meteorological Network



Santa Cruz Tenerife  
 $PM_{10} < 15 \mu g m^{-3}$



Santa Cruz Tenerife  
 $PM_{10} > 60 \mu g m^{-3}$



## Relation between horizontal visibility and TSP or PM10

Very few studies on the relation between horizontal visibility and TSP or PM10 levels of mineral dust mass concentration have been carried out in Africa.

$$C_{TSP} = 1339.84 VV^{-0.67}$$

Ben Mohamed et al. (1992)

$$C_{PM10} = 914.06 VV^{-0.73} + 19.03$$

D'Almeida's (1986)

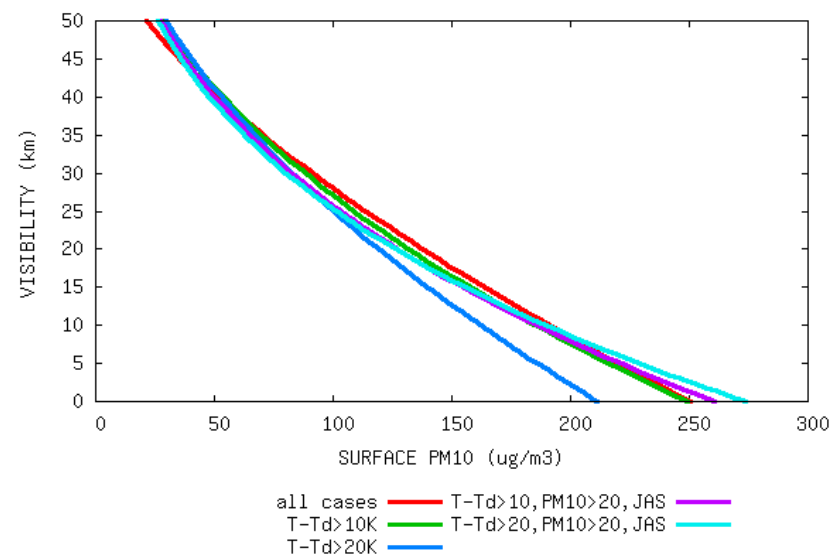
where  $C$  is the TSP concentration in  $\mu\text{gm}^{-3}$  and  $VV$  is the horizontal visibility in km

E. Terradellas

$$\text{Vis} = 63023 - 1838(\text{PM}_{10}^{0.64})$$

PM<sub>10</sub> at Izaña

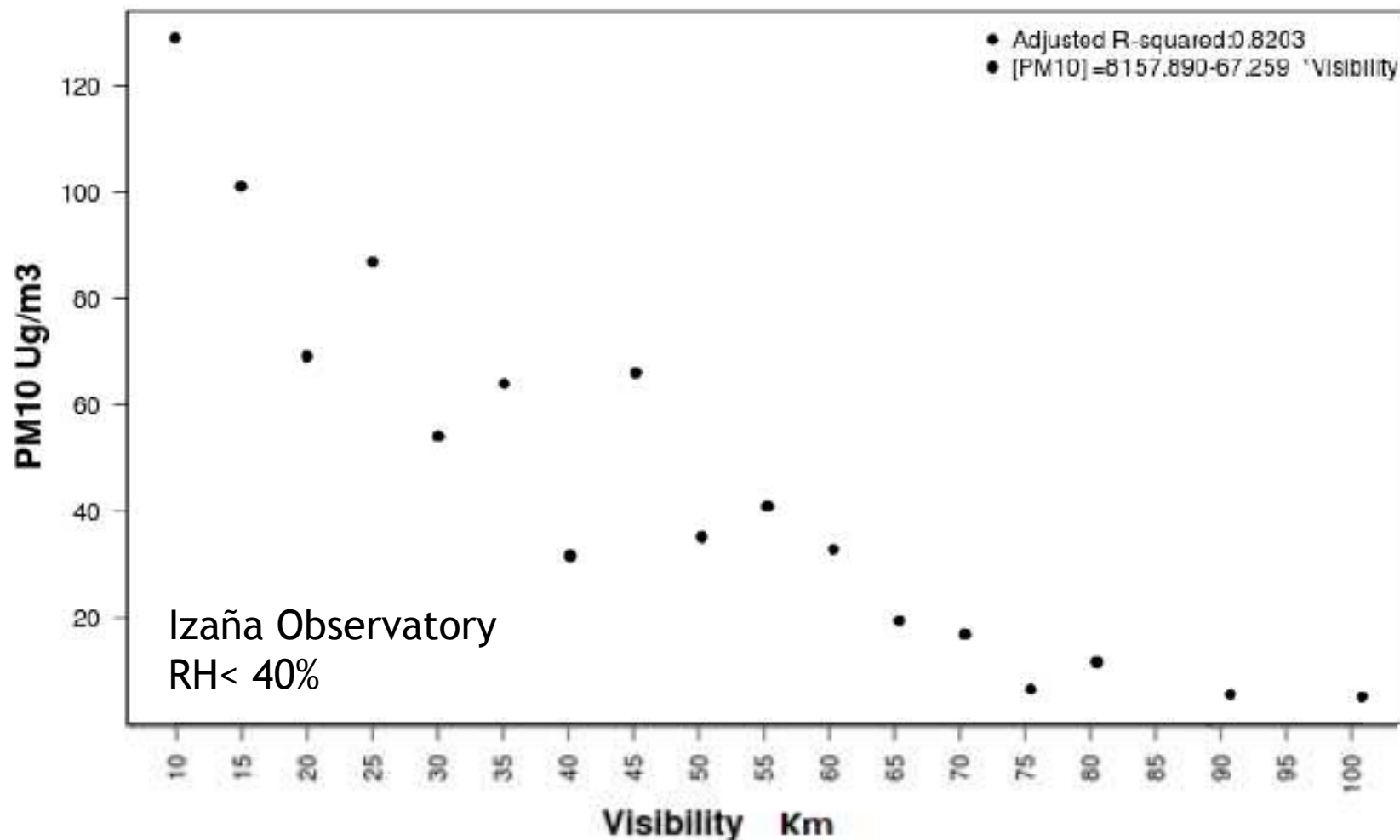
Visibility from SYNOP-Izaña



Identify surface station visibility reports that may be used in simple regression model for estimate ground PM10 or TSP

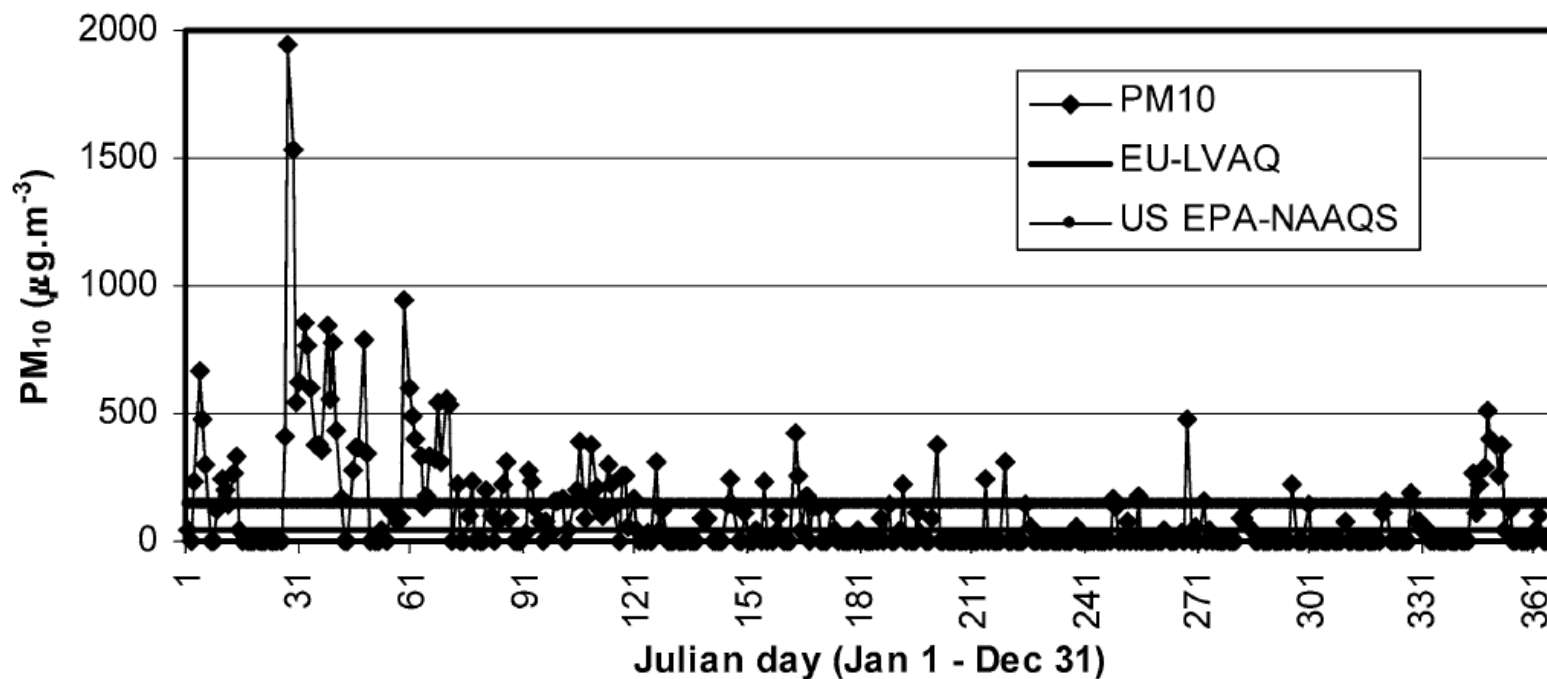
At above 60% RH, particles can experience hygroscopic growth because the water vapor can condense on the particles making them “Grow”

Scatterplot at Izaña



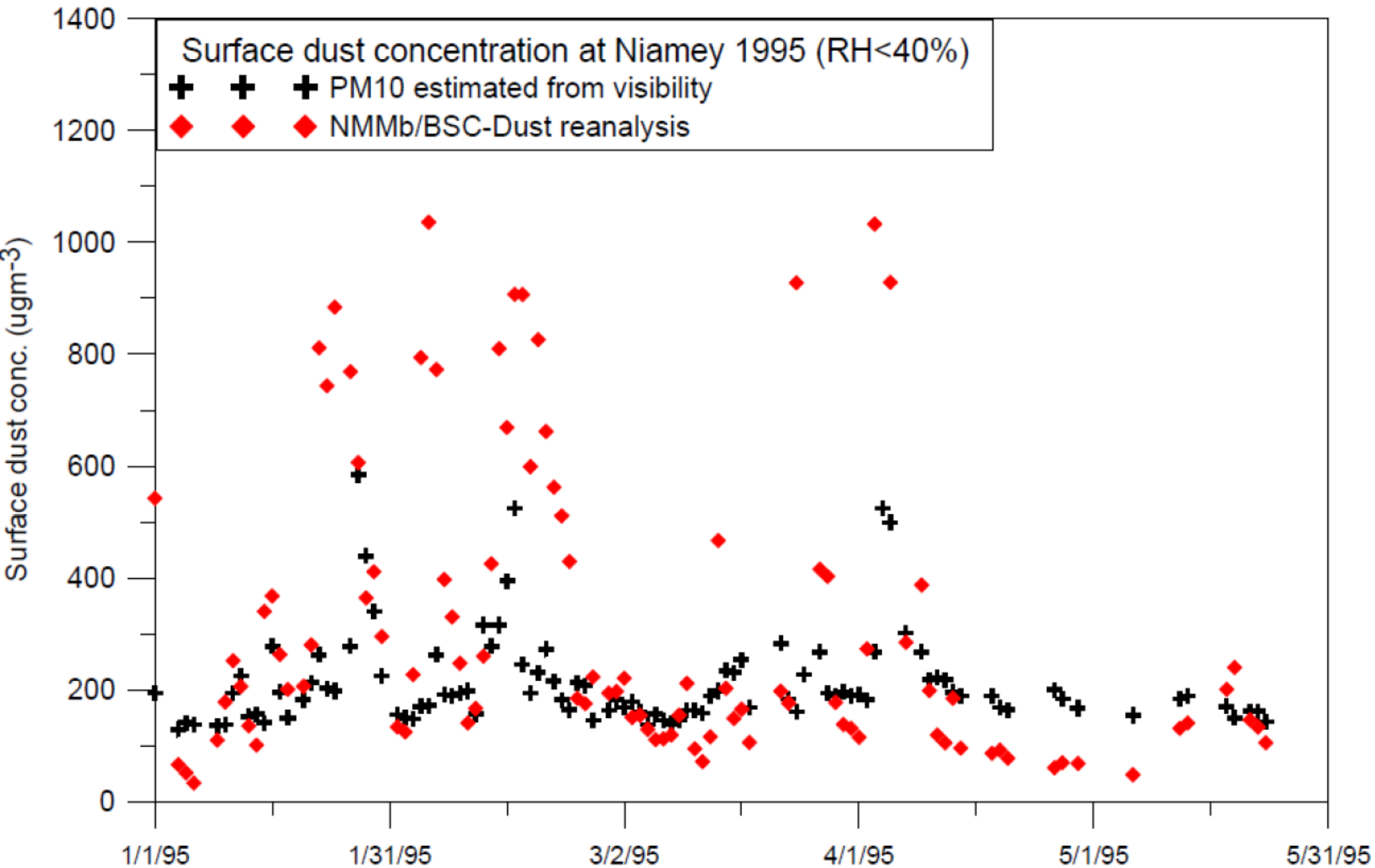


Variations of estimated daily mean concentrations of TSP and PM10 ( $\mu\text{g}\cdot\text{m}^{-3}$ ) due to Saharan dust events at Nouakchott, Mauritania, in 2000



Ozer et al., (2006): Estimation of air quality degradation due to Saharan dust at Nouakchott, Mauritania, from horizontal visibility data

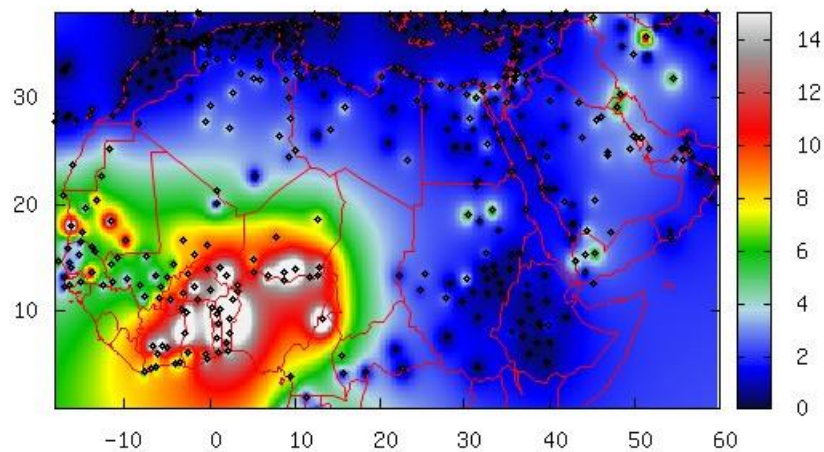




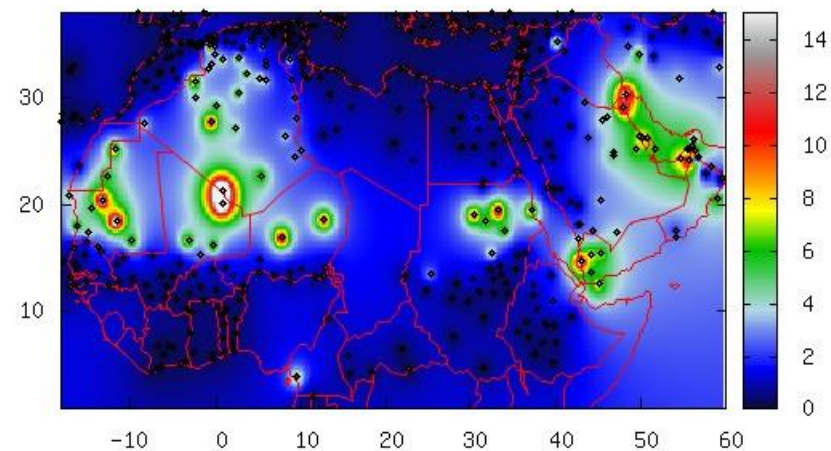
Synop and Metar reports from Met stations

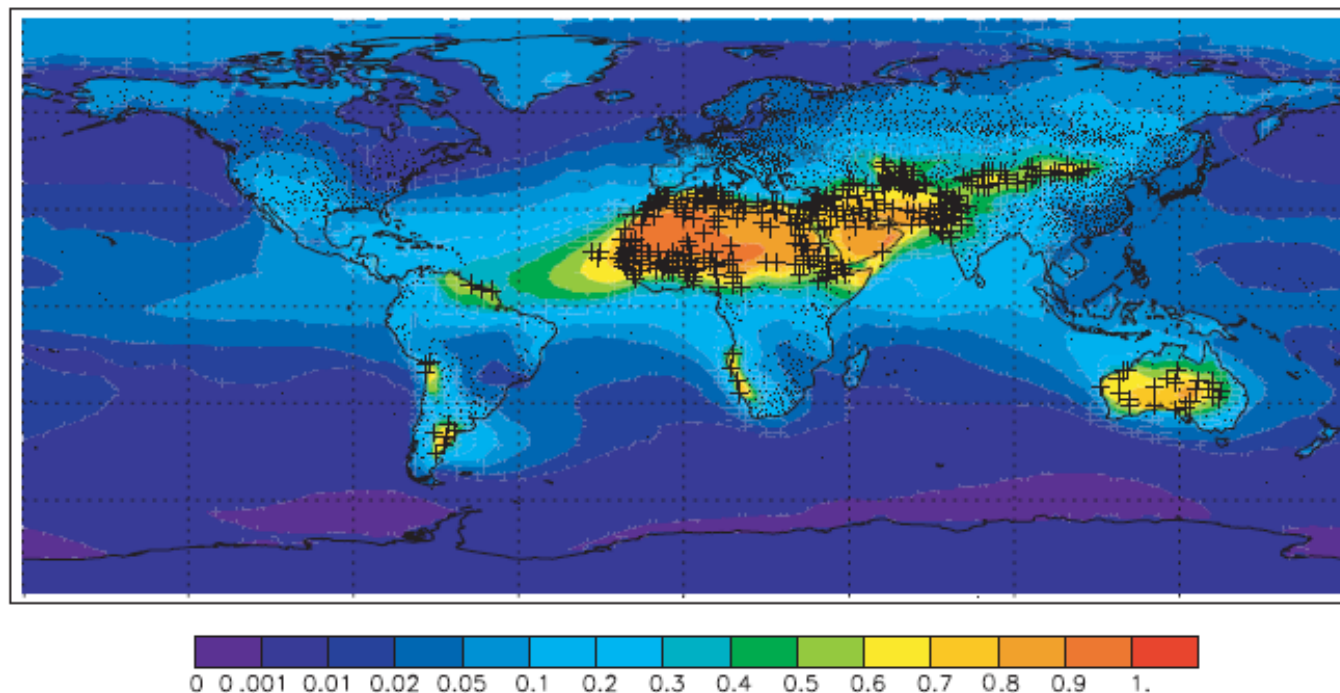
Provided by Enric Terradellas

**WINTER**



**SUMMER**





**Fig. 4.** Location of visibility stations with more than 30 years of data. Colored contours show fraction of surface extinction from desert dust. Pluses show stations in regions dominated by desert dust (>50%), while dots show other locations.

Mahowald et al. (2007) Atmos. Chem. Phys.; Global trends in visibility: implications for dust sources

## Problems with station visibility estimates

1. Human observations are inherently subjective.
2. No all reductions of visibility are due to dust (fog, biomass burning...)
3. Coarse reporting bins
4. Judgment in distinguishing visibility beyond 10 km

## Main advantages

1. Reports are abundant and widespread over land. There is information in remote areas (deserts)
2. There are *some* standards
3. Human detected visibility has been correlated well with surface extinction analyses (Husar et al., 2000)
4. Estimations of PM are possible

From ground observations...  
to total atmospheric column observations

Sunphotometers

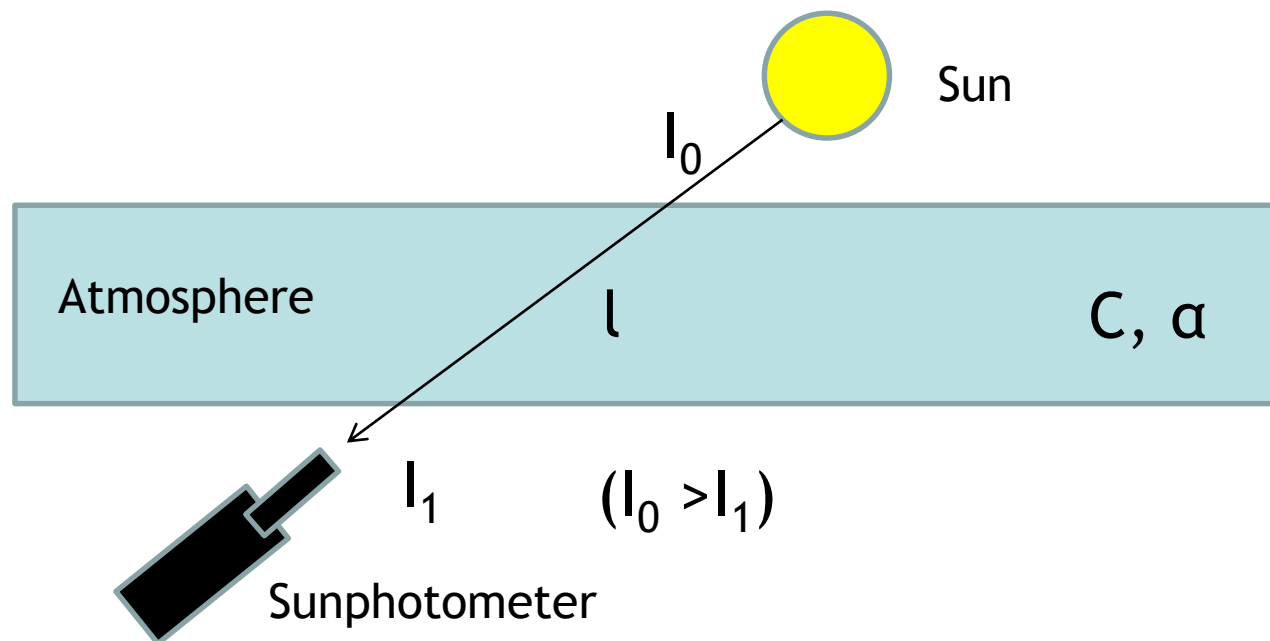


# Index

- Aerosols and dust background
- In-situ dust characterization
- In-situ dust estimations (Visibility)
- Ground based remote sensing
- Summary

## CONCEPTS:

Knowing the sunlight's energy at the top of the atmosphere, the thickness of the atmosphere, and the amount of sunlight transmitted to the earth's surface may allows us to **determine the amount of extinction**, and thus, the amount of **aerosols (dust)**.



Beer's Law

$$I = I_0 \cdot e^{-\sigma_{\text{ext}} \cdot L}$$

Transmissivity (T)

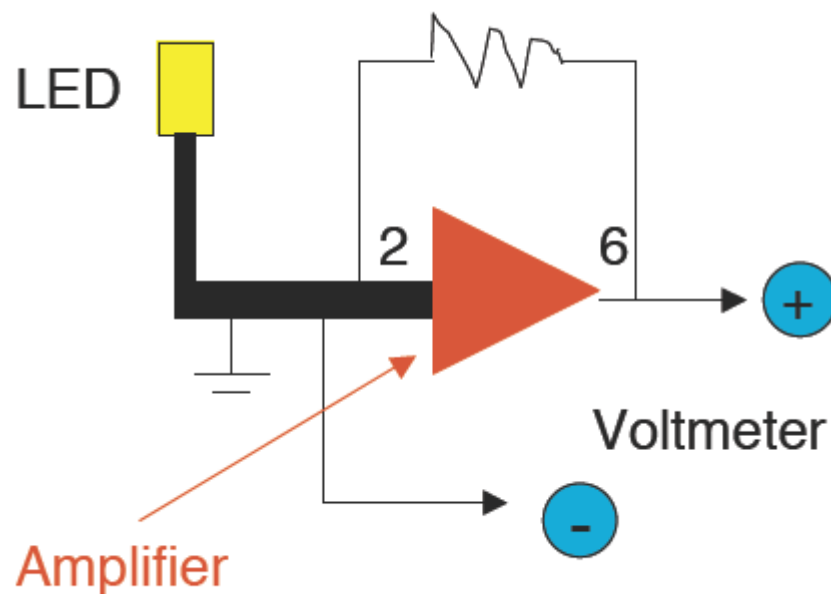
Extinction coefficient ( $\sigma_{\text{ext}}$ ):  $\epsilon C$   
path length (L)

molar absorptivity of the absorber ( $\epsilon$ )

concentration of absorbing species in the material (C)

## CONCEPTS:

**Sun Photometers** absorb *direct* sunlight energy with a LED light and convert the intensity into a quantified voltage to measure aerosols in the atmosphere.



The intensity of sunlight at the top of the earth's atmosphere is constant. While the sunlight travels through the atmosphere, aerosols can dissipate the energy by scattering (Rayleigh and Mie) and absorbing the light. More aerosols in the atmosphere cause more scattering and less energy transmitted to the surface.

## ASSESSMENT OF OBSERVATIONS CONSISTENCY

Langley plot calibration (100 determination for each wavelength):

$$I = I_0 \cdot e^{-\sigma_{\text{ext}} \cdot L}$$

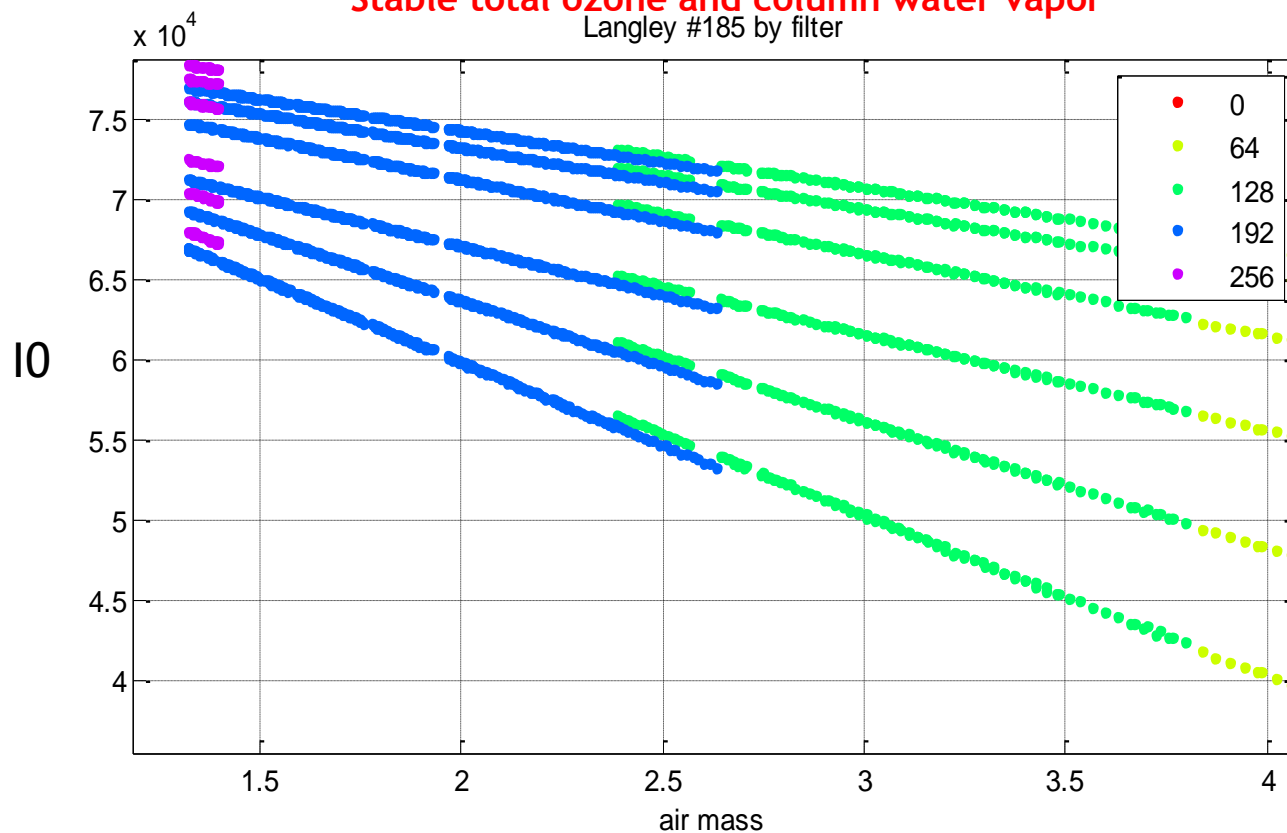
$$\ln I = \ln I_0 - \sigma_{\text{ext}} L$$

If  $\sigma_{\text{ext}}$  is constant during the observation  We can determine  $I_0$

**Pristine conditions (very low and constant aerosol load)**

**No clouds**

**Stable total ozone and column water vapor**



## CONCEPTS:

**Aerosol Extinction:** A measure of attenuation of the light passing through the atmosphere due to scattering and absorption by aerosol particles.

**Extinction coefficient ( $\sigma_{\text{ext}}$ )** is the fractional depletion of radiance per unit path length (also called attenuation). It has units of  $\text{km}^{-1}$ .

**Aerosol Mass Load:** The columnar aerosol mass concentration ( $\mu\text{g}/\text{cm}^2$ ) is the total aerosol mass in a vertical column of atmosphere.

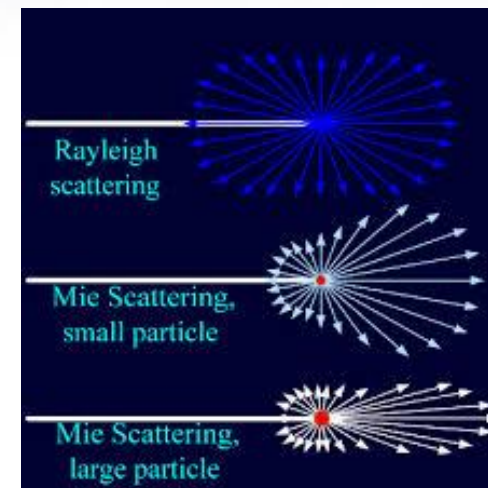


## CONCEPTS:

**Aerosol Asymmetry Factor** A measure of the preferred scattering direction (forward or backward) for light encountering aerosol particles.

$$g = \frac{1}{2} \int_{-1}^{+1} \cos \Theta P(\cos \Theta) d \cos \Theta$$

$$P(\cos \Theta) = \frac{1 - g^2}{(1 + g^2 - 2g \cos \Theta)^{3/2}}$$



In general,  **$g=0$  indicates scattering directions evenly distributed** between forward and backward directions, i.e. isotropic scattering (e.g. scattering from small particles)

**$g < 0$  scattering in the backward direction** (i.e scattering angle  $> 90$  deg.), often referred to as backscattering, is scattering at  $180$  deg.

**$g > 0$  scattering in the forward direction** (i.e scattering angle  $< 90$  deg.), often referred to as forward-scattering, is scattering at  $0$  deg. **For larger size or Mie particles,  $g$  is close to  $+1$ . Including DUST**

## CONCEPTS:

### Aerosol Optical Depth (or Thickness)

"Aerosol Optical Depth" (AOD) is the degree to which aerosols prevent the transmission of light. The aerosol optical depth or optical thickness ( $\tau$ ) is defined as the integrated extinction coefficient over a vertical column of unit cross section.

$$AOD = \int_{z=0}^{z=toa} \sigma_{ext}(z) dz$$

### Angstrom Exponent ( $\alpha$ )

An exponent that expresses the spectral dependence of Aerosol Optical Depth ( $\tau$ ) with the wavelength of incident light ( $\lambda$ ). The spectral dependence of aerosol optical thickness can be approximated (depending on size distribution) by:

$$AOD = \beta \lambda^{-\alpha}$$

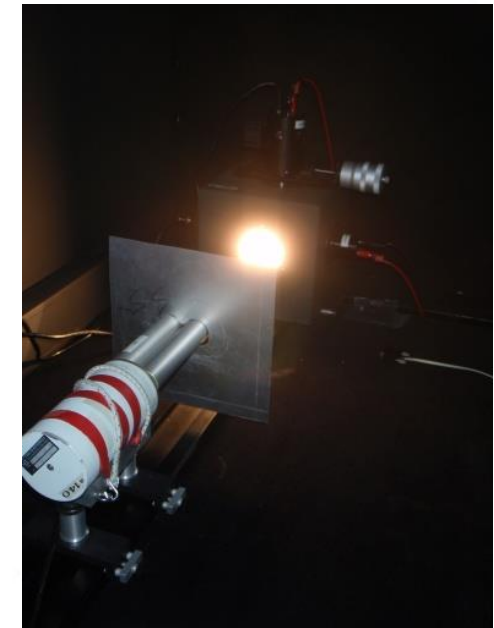
$\alpha \gg 0.9$  FINE particles

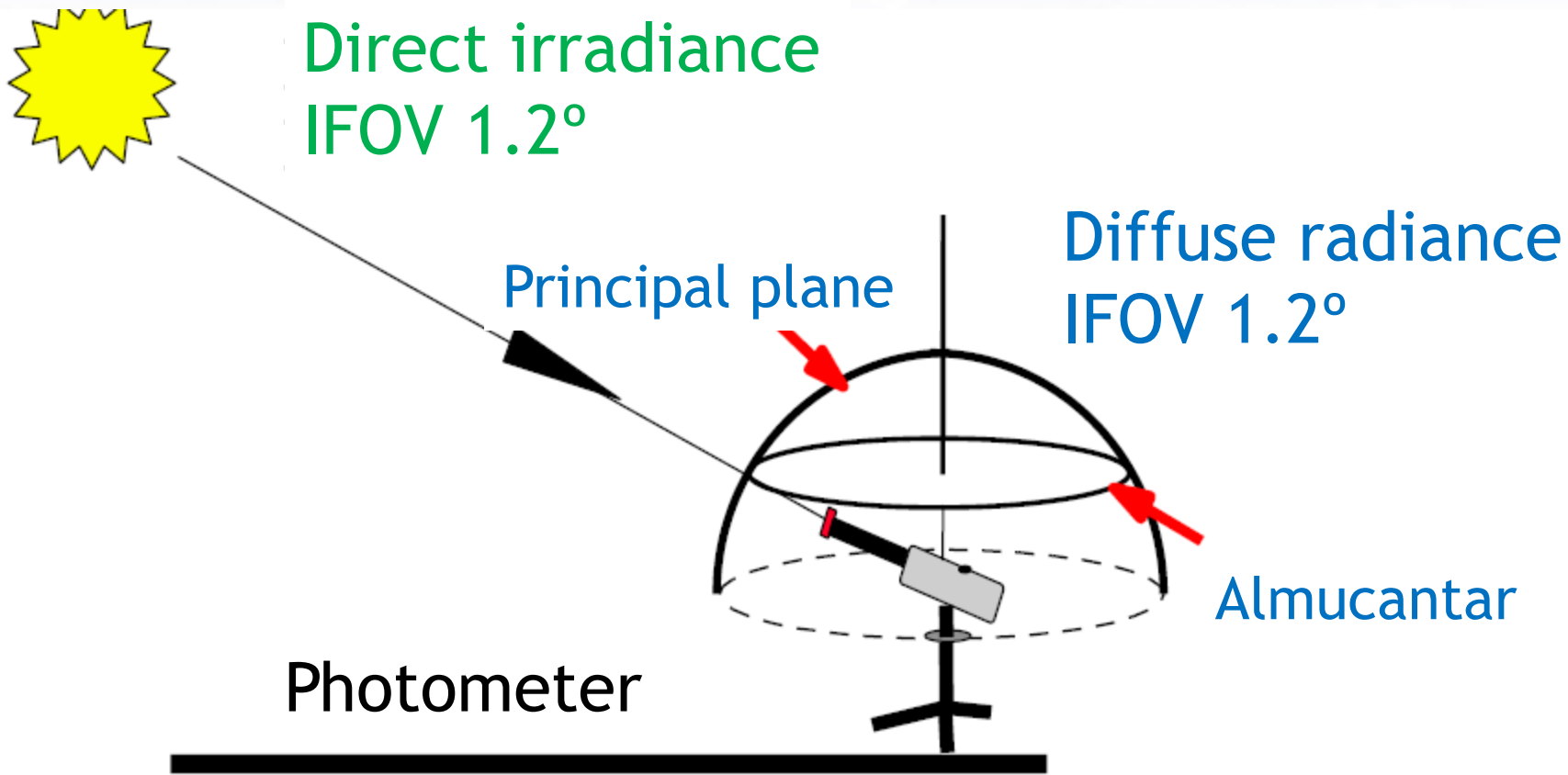
$\alpha \ll 0.7$  COARSE particles

where  $\alpha$  is the Angstrom exponent ( $\beta$  = aerosol optical depth at 1  $\mu\text{m}$ )

i.e. If  $AOD > \sim 0.2$  and  $\alpha < 0.7$  then we are observing dust (aprox.)

- The Cimel Electronique 318 spectral radiometer is a solar-powered, weather-hardy, robotically-pointed sun and sky spectral sun photometer.
- A sensor head points the sensor head at the sun according to a preprogrammed routine.
- The Cimel controller, batteries, and the optional Vitel satellite transmission equipment are usually deployed in a weatherproof plastic case.





Sun measurements  
Sky measurements

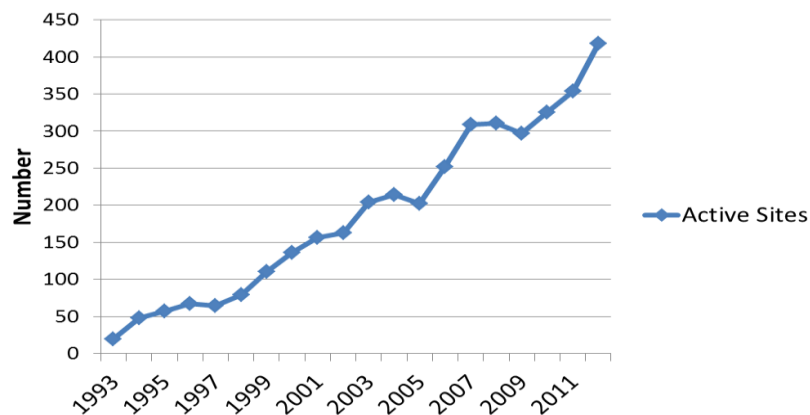


## AERONET Aerosol Robotic Network-Twenty Years of Observations and Research

15 May  
1993

15 May  
2013

AERONET Growth (1993-2012)



The **AERONET program** is a federation of ground-based remote sensing aerosol networks established by NASA and LOA-PHOTONS (CNRS) and has been expanded by collaborators from international agencies, institutes, universities, individual scientists and partners.



- >7000 citations
- >400 sites
- Over 80 countries
- <http://aeronet.gsfc.nasa.gov>

**AERONET** provides a long-term, continuous public database of aerosol optical, microphysical, and radiative properties for aerosol research and characterization, validation of satellite measurements, and synergism with other databases.



# AERONET Data Flows

<http://aeronet.gsfc.nasa.gov>

## Flux measurements

Direct -  $\lambda=340, 380, 440, 500, 670, 870, 940, 1020$  nm

Diffuse -  $\lambda=440, 670, 870, 1020$  nm (alm, pp, pol)

## Calibration and processing information

Mauna-Loa and Izaña

CNRS-University of Lille and University of Valladolid

## Aerosol optical depth and precipitable water computations

## Cloud screening and quality control

## Inversion products

Volume size distribution ( $0.05 < \text{size} < 15 \mu\text{m}$ ),  
refractive index, single scattering albedo  
( $\lambda=440, 670, 870, 1020$  nm)

Holben et al.  
*RSE*, 1998  
Holben et al.  
*JGR*, 2001

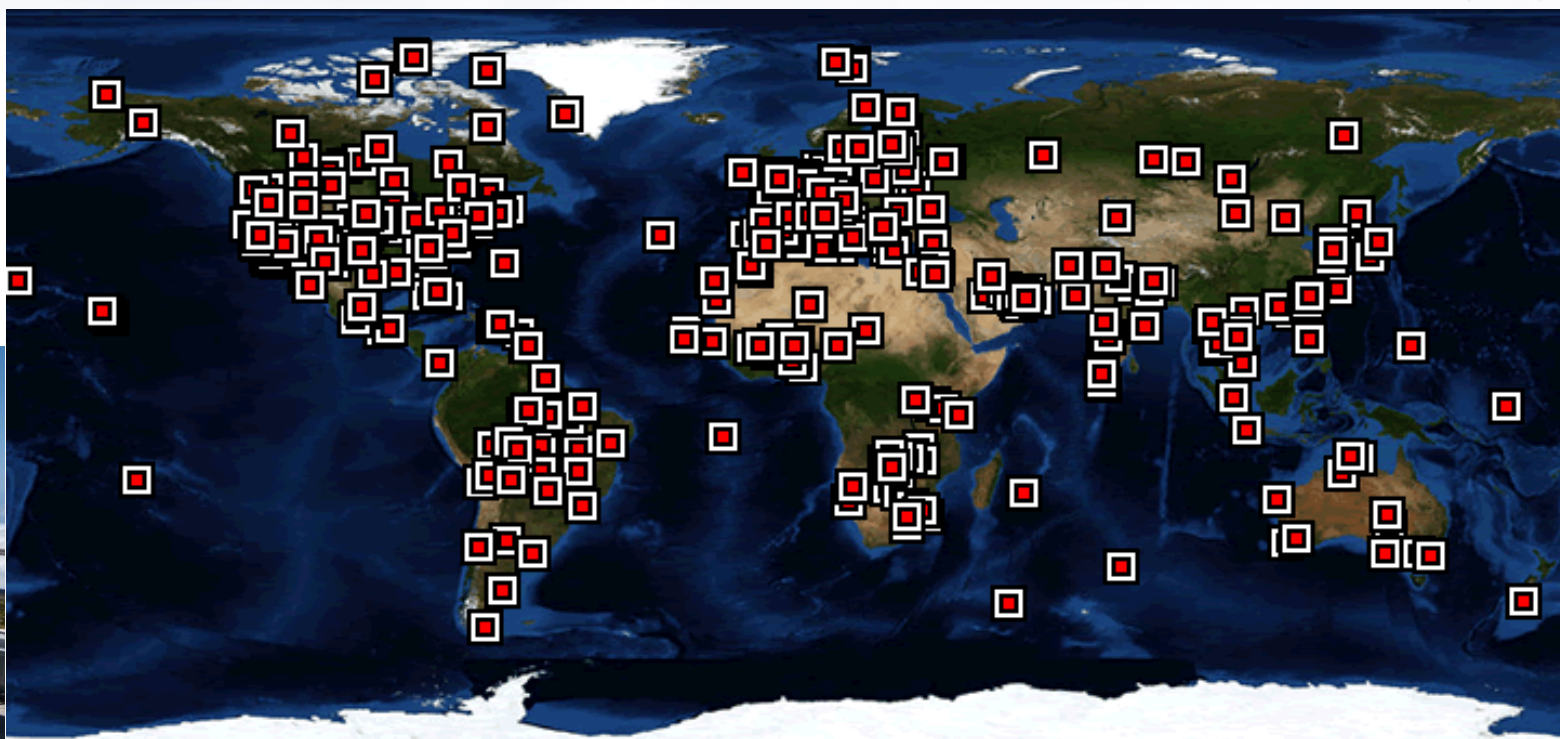
Eck et al.  
*JGR*, 1999

Smirnov et al.  
*RSE*, 2000

Dubovik and King  
*JGR*, 2000  
Dubovik et al.  
*JGR*, 2000  
*GRL*, 2002

## AERONET (AErosol RObotic NETwork)-

<http://aeronet.gsfc.nasa.gov>



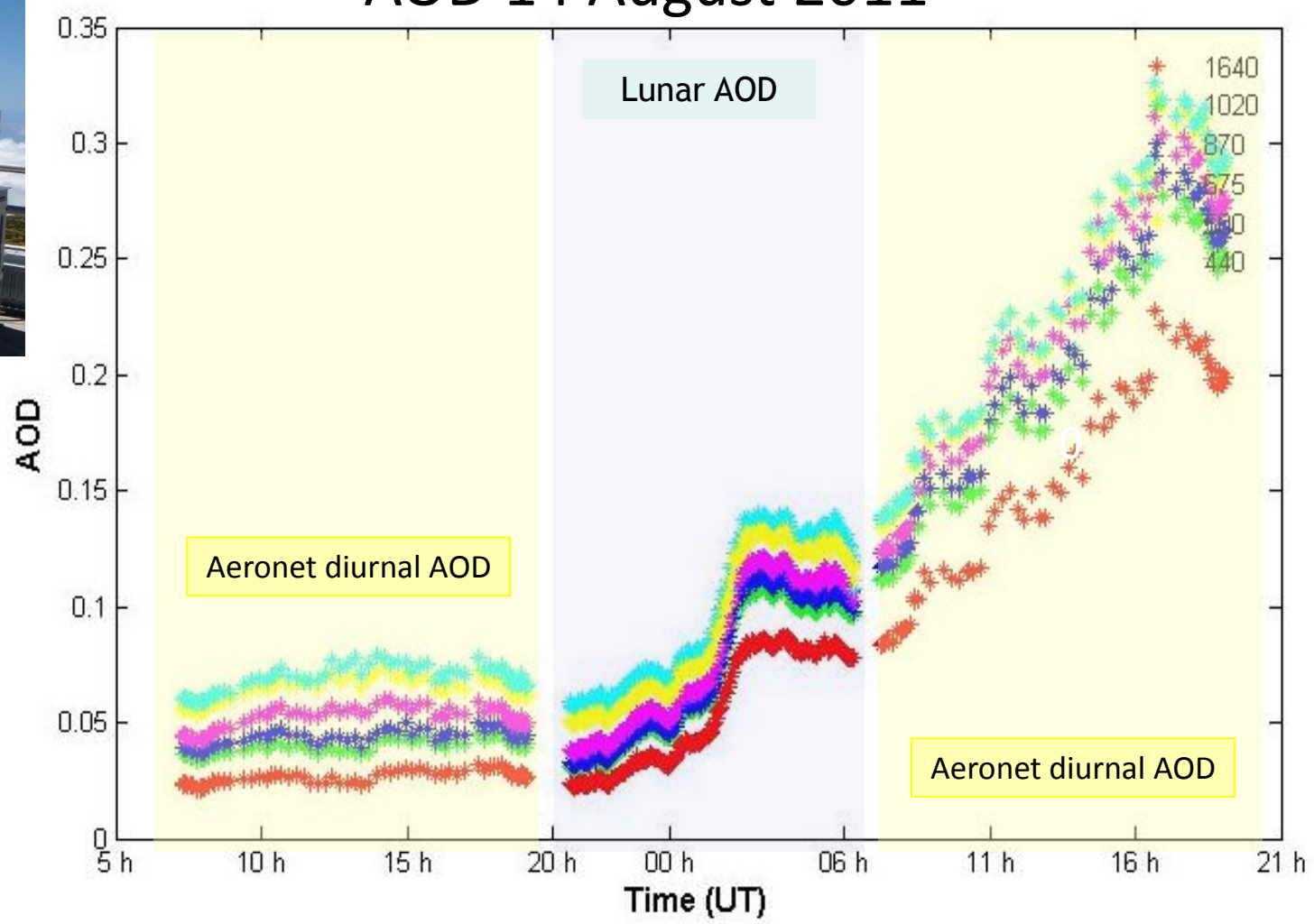
An internationally Federated Network

- Characterization of aerosol optical properties
- Validation of satellite aerosol retrieval
- Near real-time acquisition; long term measurements

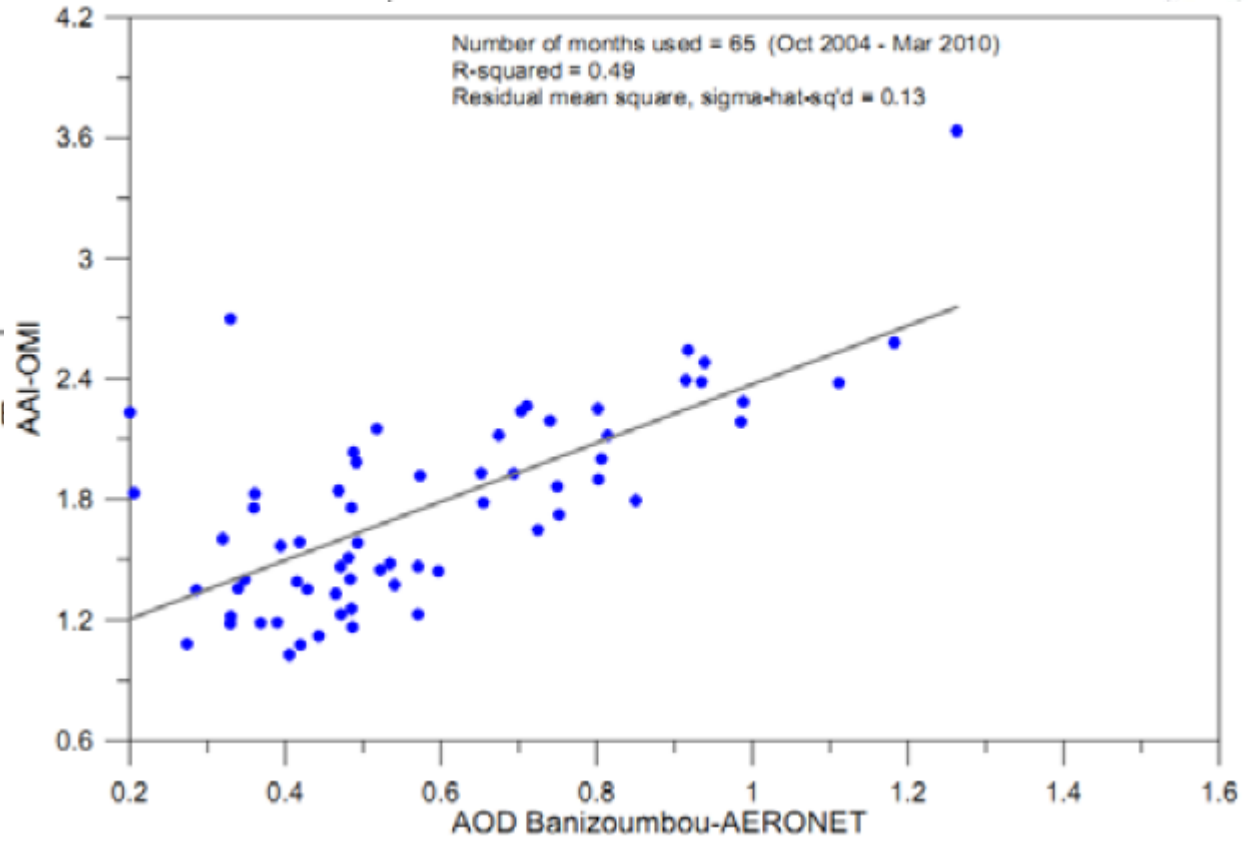
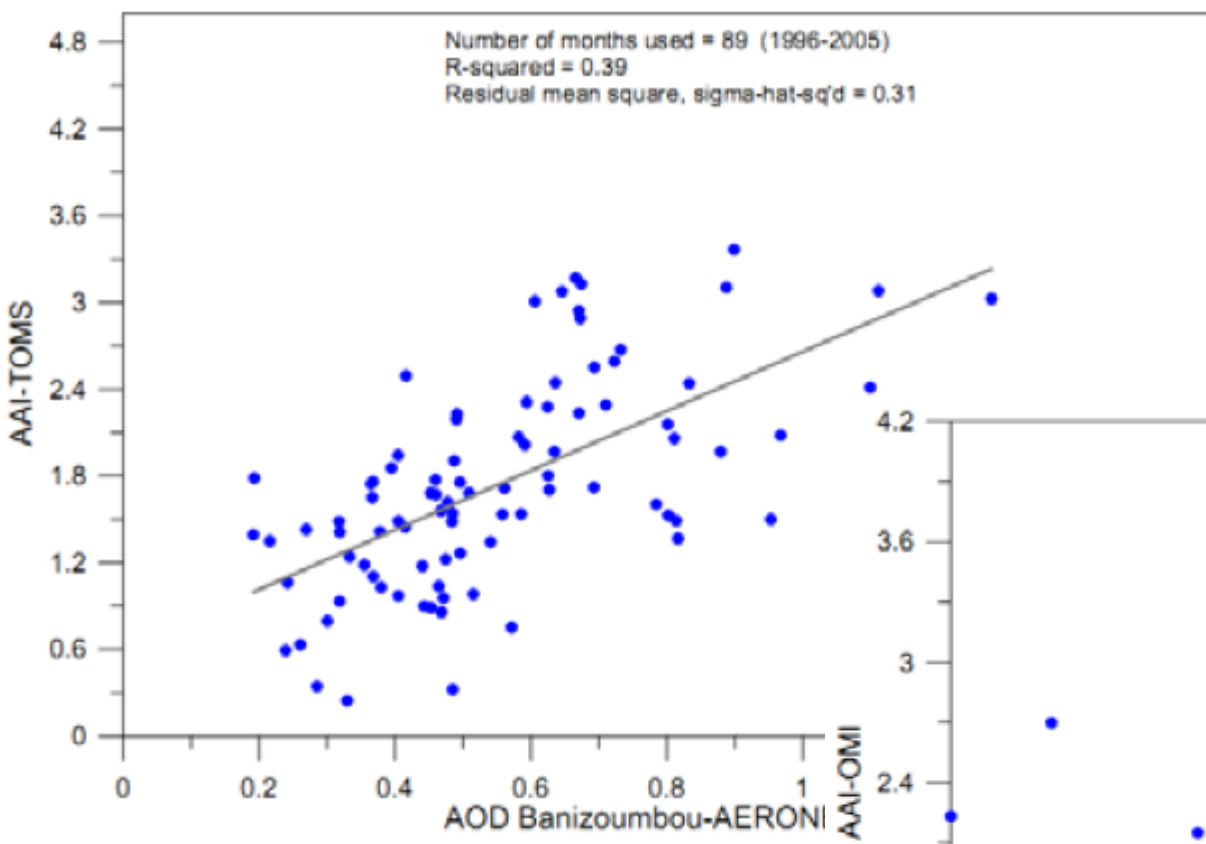
AERONET provides:

- global Aerosol Optical Depth of Dust in near real-time
- robust optical properties of Dust: size distribution, ref. Index, etc. (e.g. Asian Dust has stronger and less spectral dependent absorption than Saharan Dust)
- climatological models that reproduce observed optical properties of aerosol (useful for satellite retrievals)

# AOD 14 August 2011

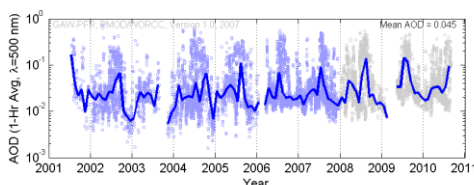
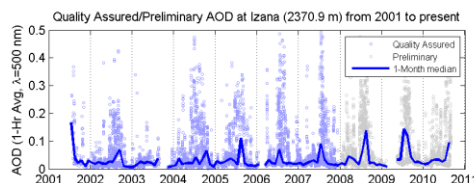
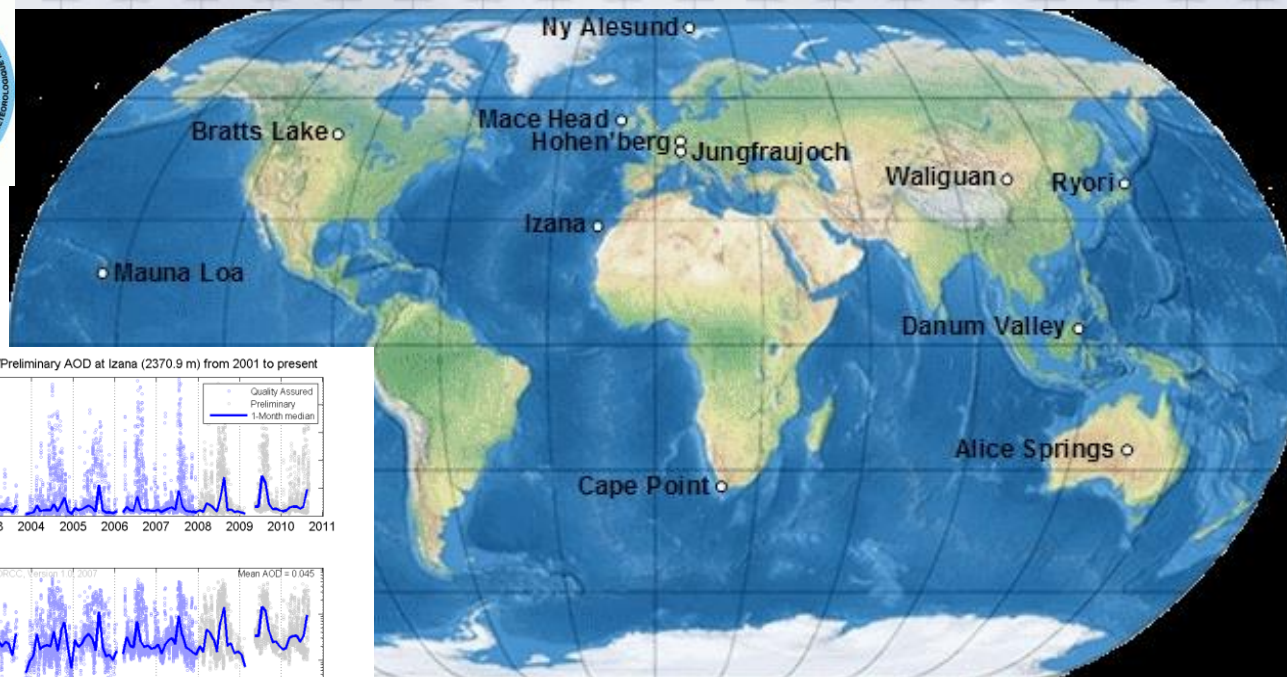








## GAW-PFR AOD Network



- Classic extinction measurements at the recommended 4 WMO wavelengths 368, 415, 500 and 862 nm using Precision Filter Radiometers (PFRs).
- Continuous sampling at a 1- minute frequency by automated systems.
- Data products: **AOD** and the **Angström coefficients alpha** and **beta** (no inversions).
- Hourly mean AOD archived at the World Data Center for Aerosols (WDCA). Data with a 1-minute resolution are available from WORCC upon request.

GAW-PFR provides:

- long-term high-accuracy AOD and Angström Coefficients
- GAW-PFR provides AOD Dust in near real-time

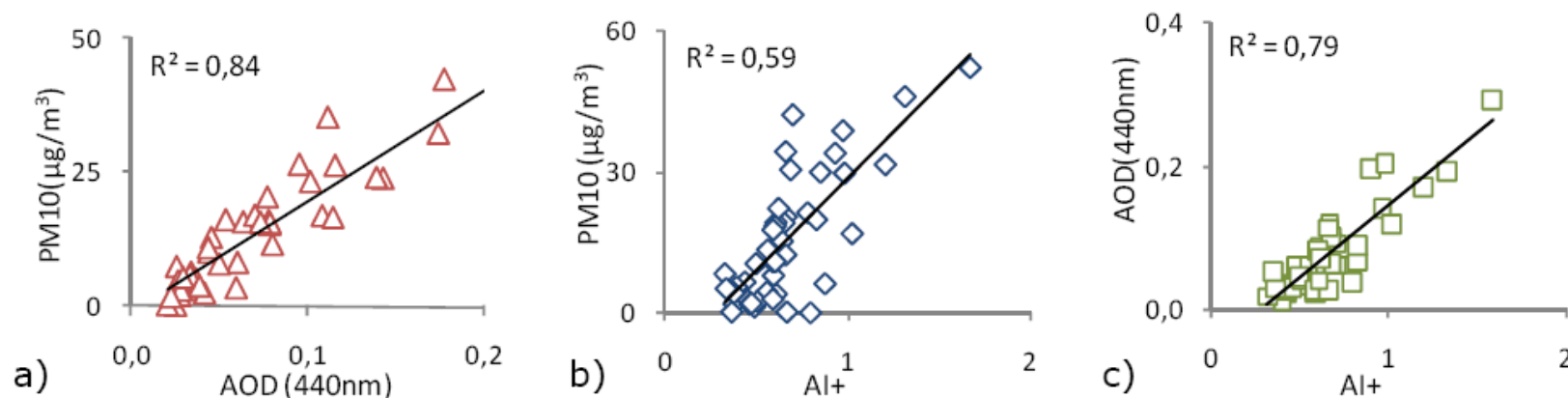


Figure 1. Scatterplot of monthly means of a) AOD vs  $PM_{10}$ ; b) AI positive values vs  $PM_{10}$ ; c) AI positive values vs AOD.

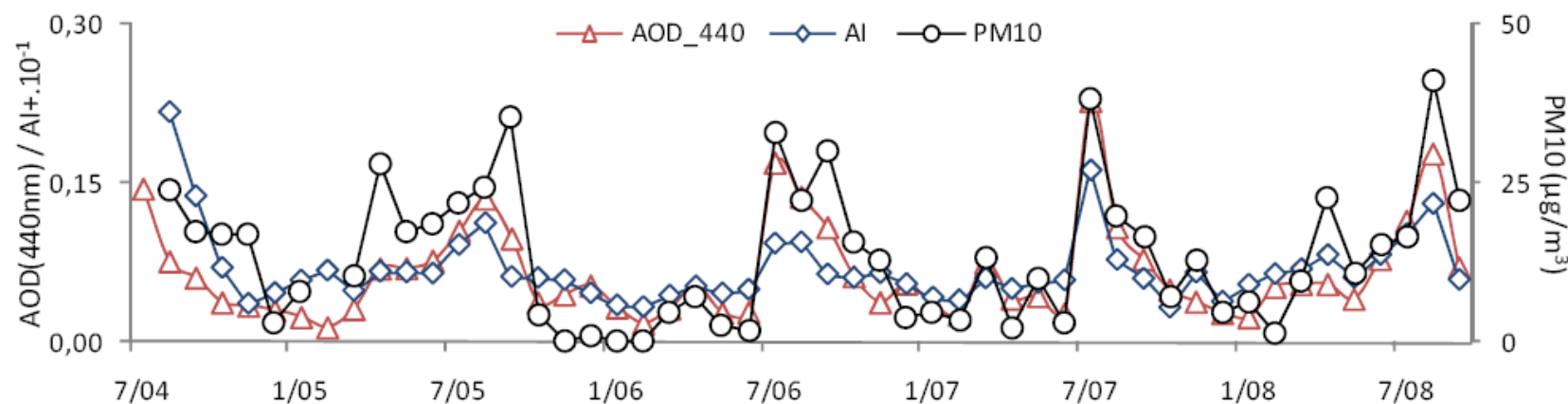


Figure 2. Monthly means of  $PM_{10}$  ( $\mu g/m^3$ ), AOD and AI positive values.

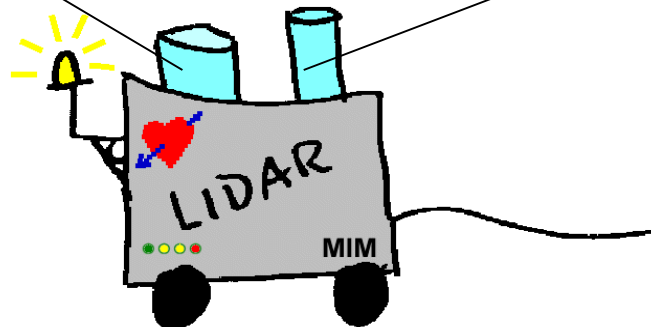
Adam et al., 2010 (ACP-Interlaken): Detection of the Saharan dust air layer in the North Atlantic free troposphere with AERONET, OMI and in-situ data at Izaña Atmospheric Observatory

From total column observations...  
to vertical resolved observations

Lidars

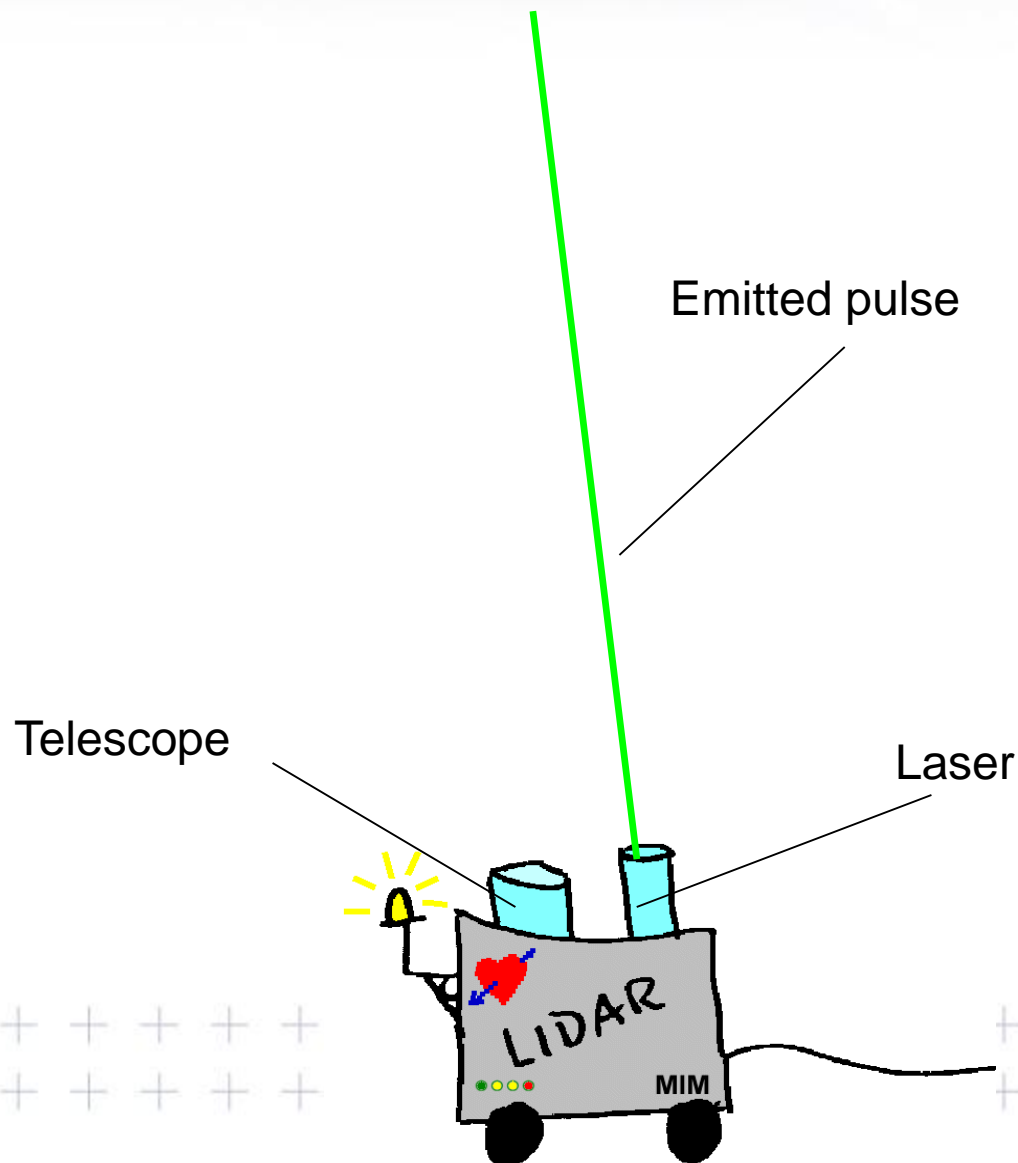
Telescope

Laser

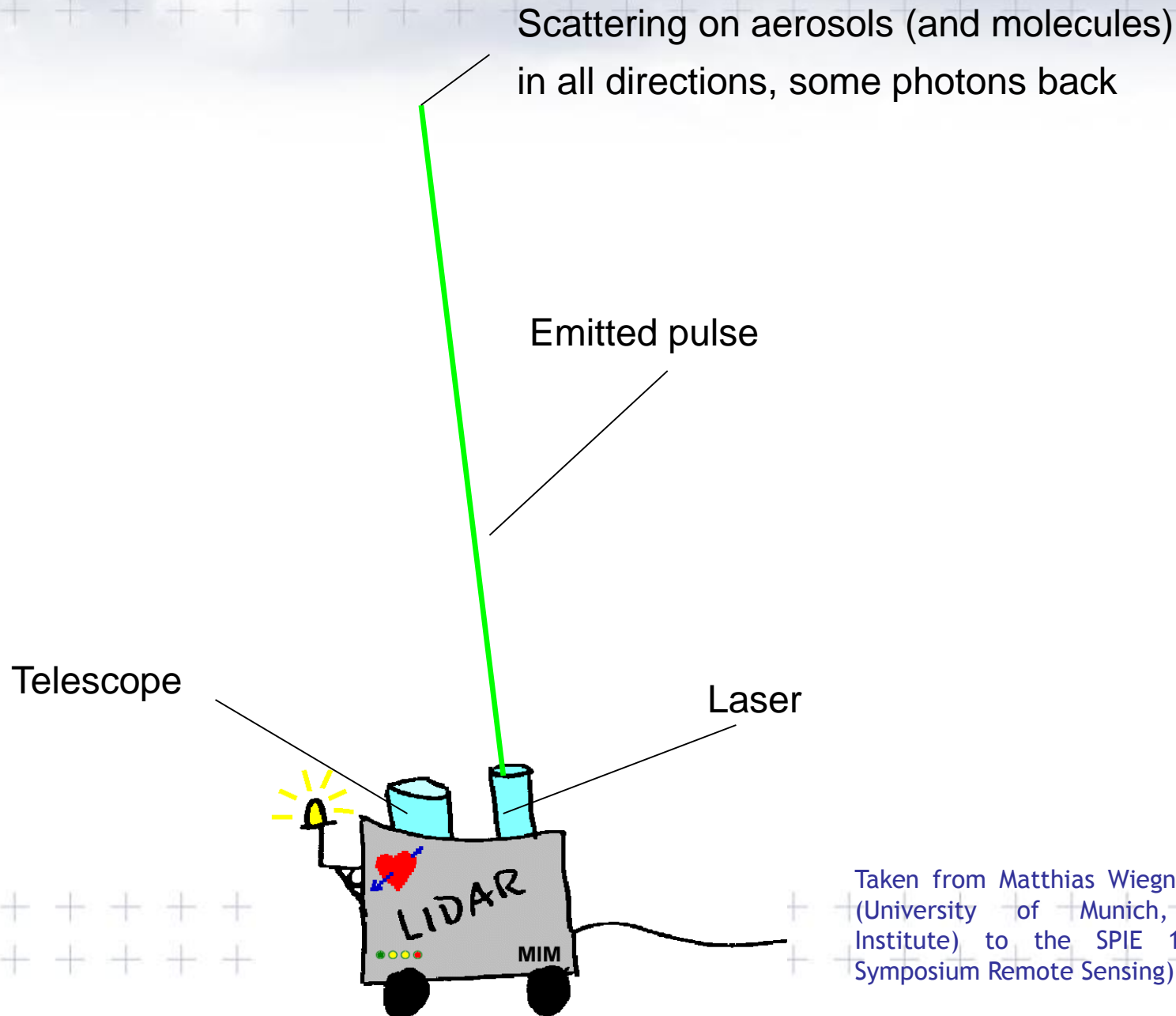


Taken from Matthias Wiegner's presentation  
(University of Munich, Meteorological  
Institute) to the SPIE 10 (International  
Symposium Remote Sensing)

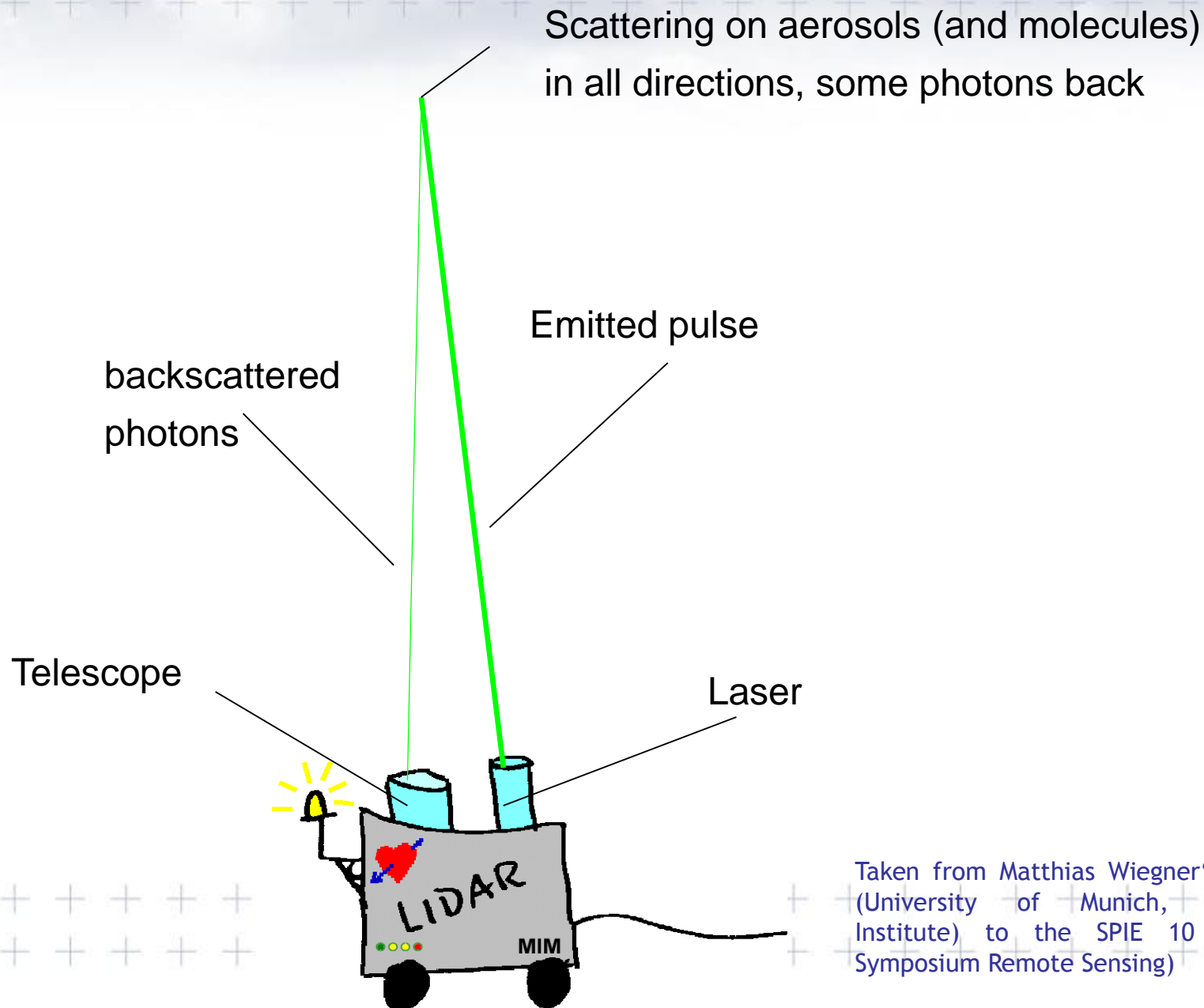




Taken from Matthias Wiegner's presentation (University of Munich, Meteorological Institute) to the SPIE 10 (International Symposium Remote Sensing)



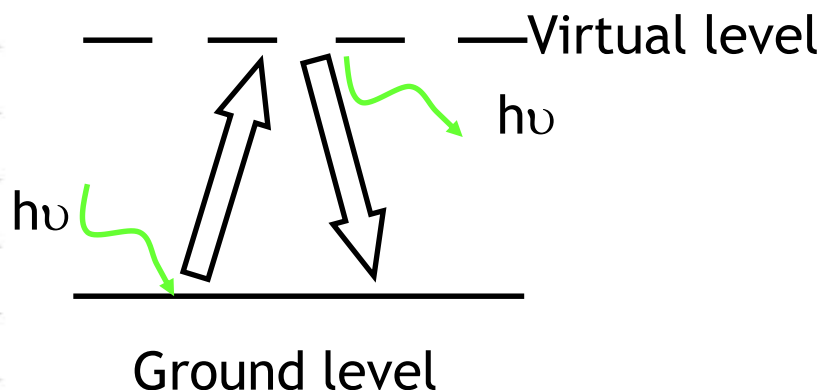
Taken from Matthias Wiegner's presentation (University of Munich, Meteorological Institute) to the SPIE 10 (International Symposium Remote Sensing)



Taken from Matthias Wiegner's presentation (University of Munich, Meteorological Institute) to the SPIE 10 (International Symposium Remote Sensing)

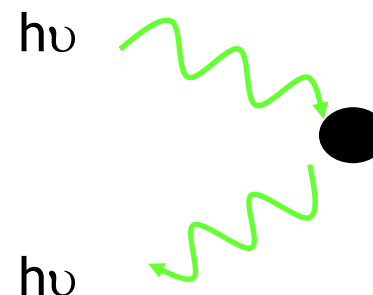
- Rayleigh Scattering

“Laser radiation elastically scattered from atoms or molecules is observed with no change of frequency”



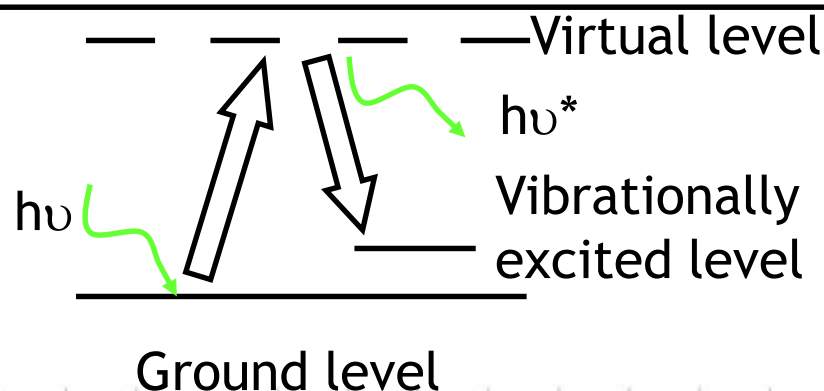
- Mie Scattering

“Laser radiation elastically scattered from small particulates or aerosols (of size comparable to wavelength of radiation) is observed with no change in frequency”



- Raman Scattering

“Laser radiation inelastically scattered from molecules is observed with a frequency shift characteristic of the molecule ( $h\nu - h\nu^* = E$ )”







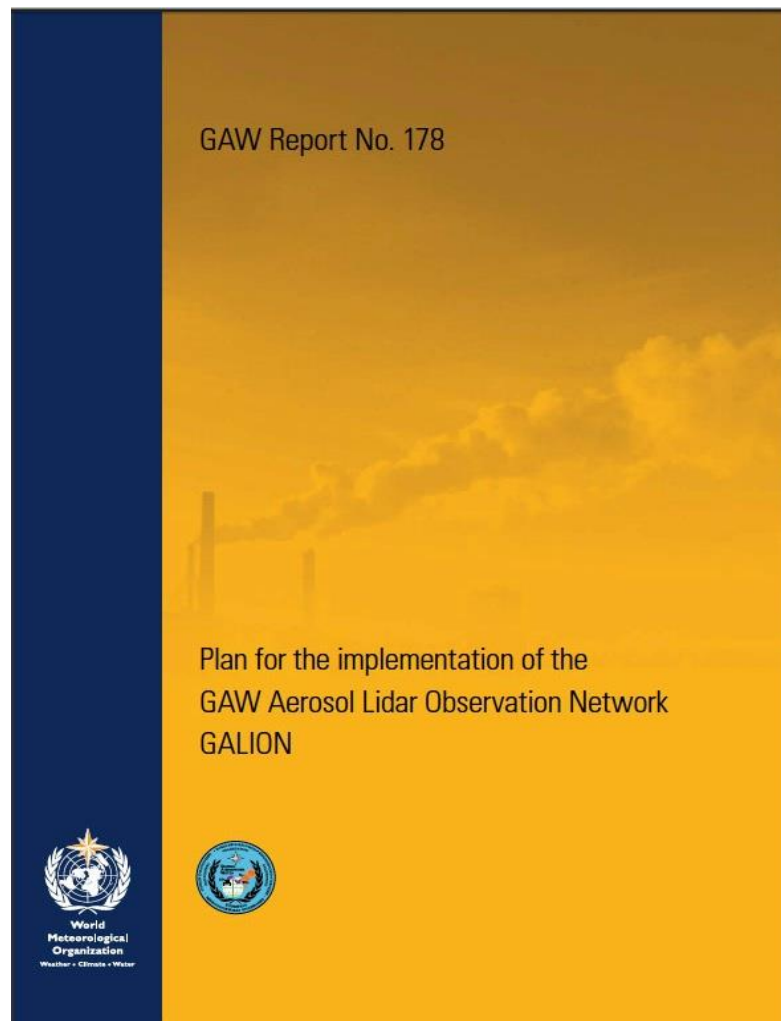
Lidar-Barcelona (UPC)  
Raman Lidar  
EARLINET-SPALINET



Lidar-Tenerife (INTA-AEMET); Elastic lidar  
MPLNET

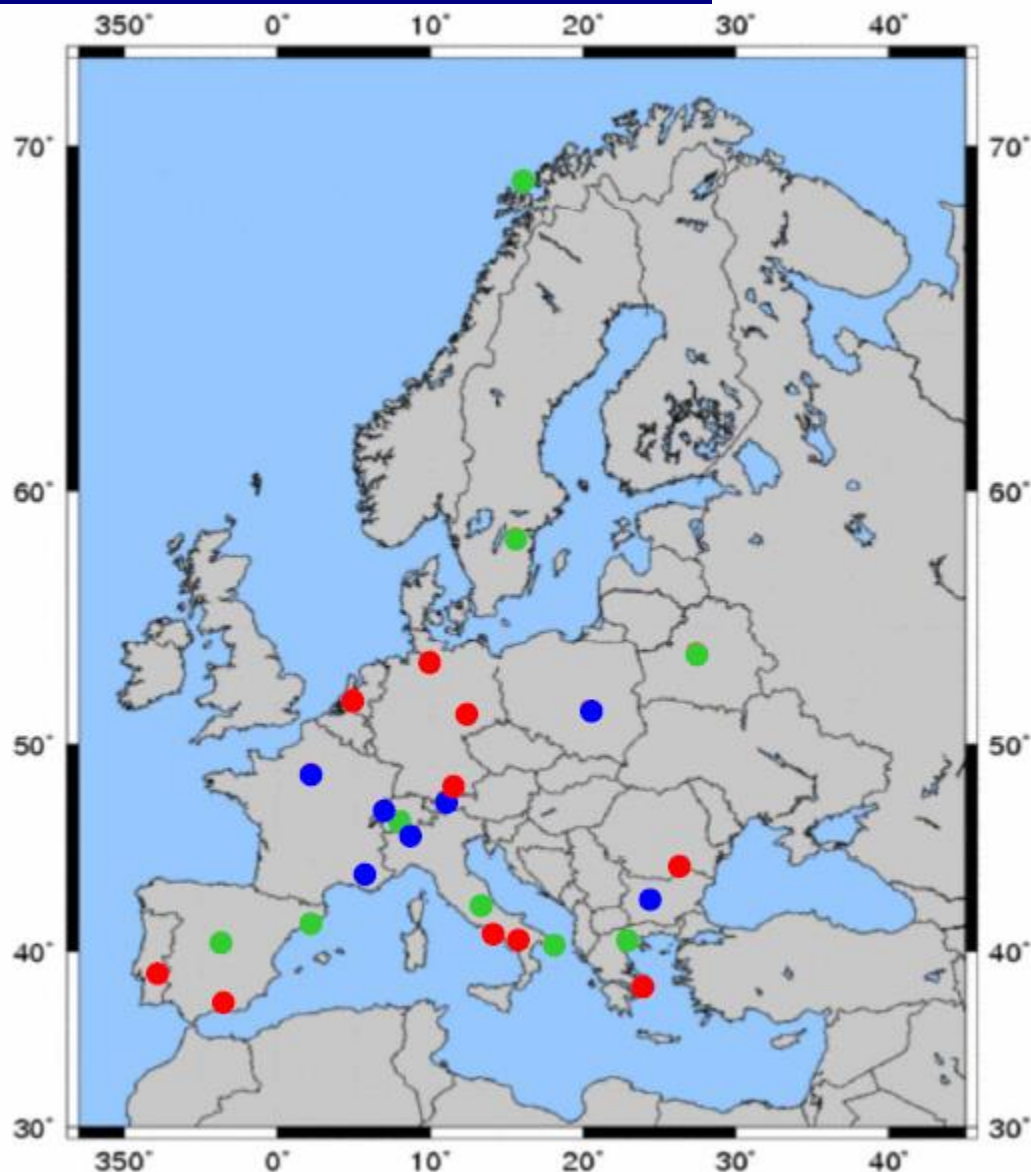


## GAW Atmospheric Lidar Network (GALION)



[ftp://ftp.wmo.int/Documents/  
PublicWeb/arep/gaw/gaw178-  
galion-27-Oct.pdf](ftp://ftp.wmo.int/Documents/PublicWeb/arep/gaw/gaw178-galion-27-Oct.pdf)





## EARLINET

**EARLINET (European Aerosol Research Lidar NETwork)** is a network of advanced lidar stations distributed over Europe with the main goal to provide a comprehensive, quantitative, and statistically significant data base for the aerosol distribution on a continental scale. EARLINET provides independent measurements of aerosol extinction and backscatter, and retrieval of aerosol microphysical properties.

10 EARLINET stations are equipped also with sunphotometers (they are part of AERONET).

### 26 lidar stations

- 10 multiwavelength Raman lidar stations

backscatter (355, 532 and 1064 nm)  
+ extinction (355 and 532 nm) +  
depolar ratio (532 nm)

- 9 Raman lidar stations

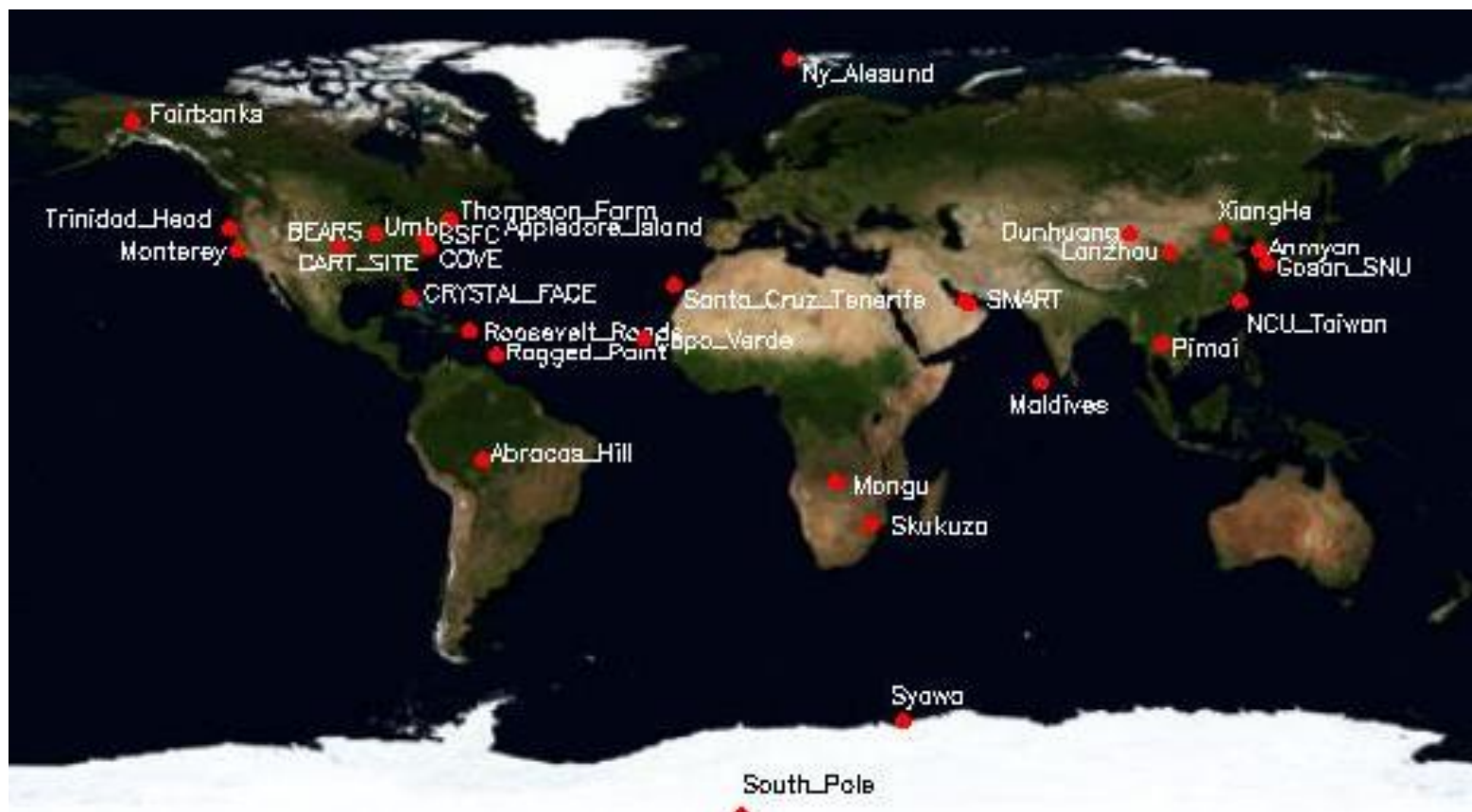
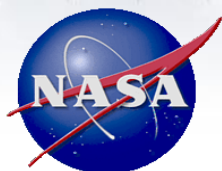
- 7 single backscatter lidar stations

## Aerosol lidar (MPLNet)

<http://mplnet.gsfc.nasa.gov/>

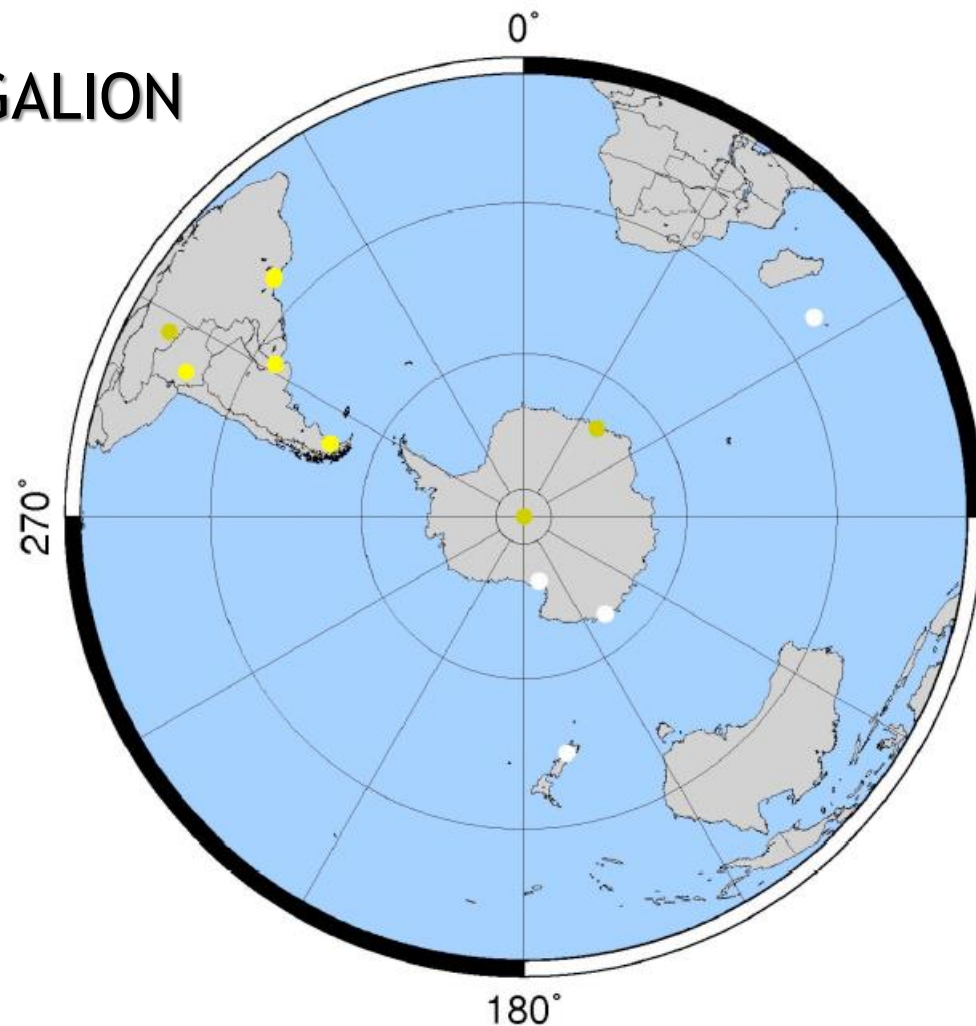
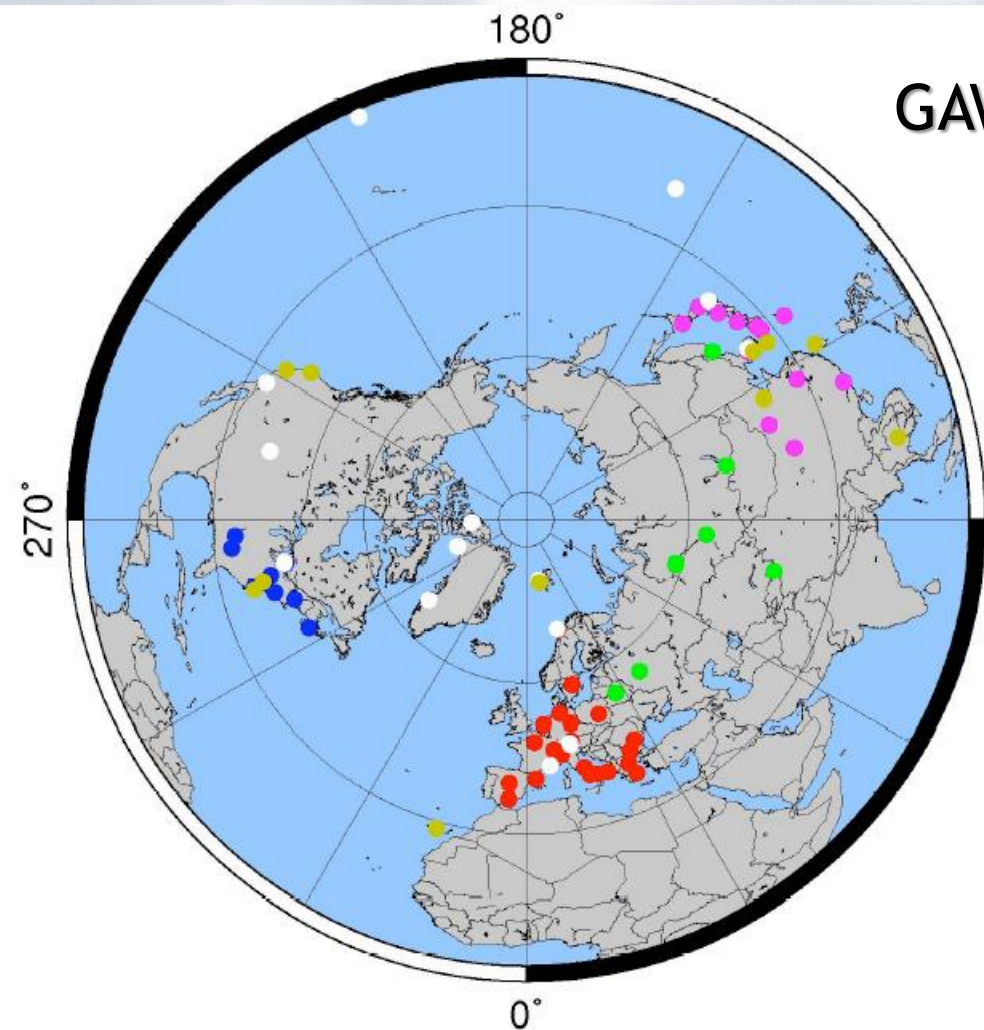
523 nm MPLNET

Automatized since July 2005



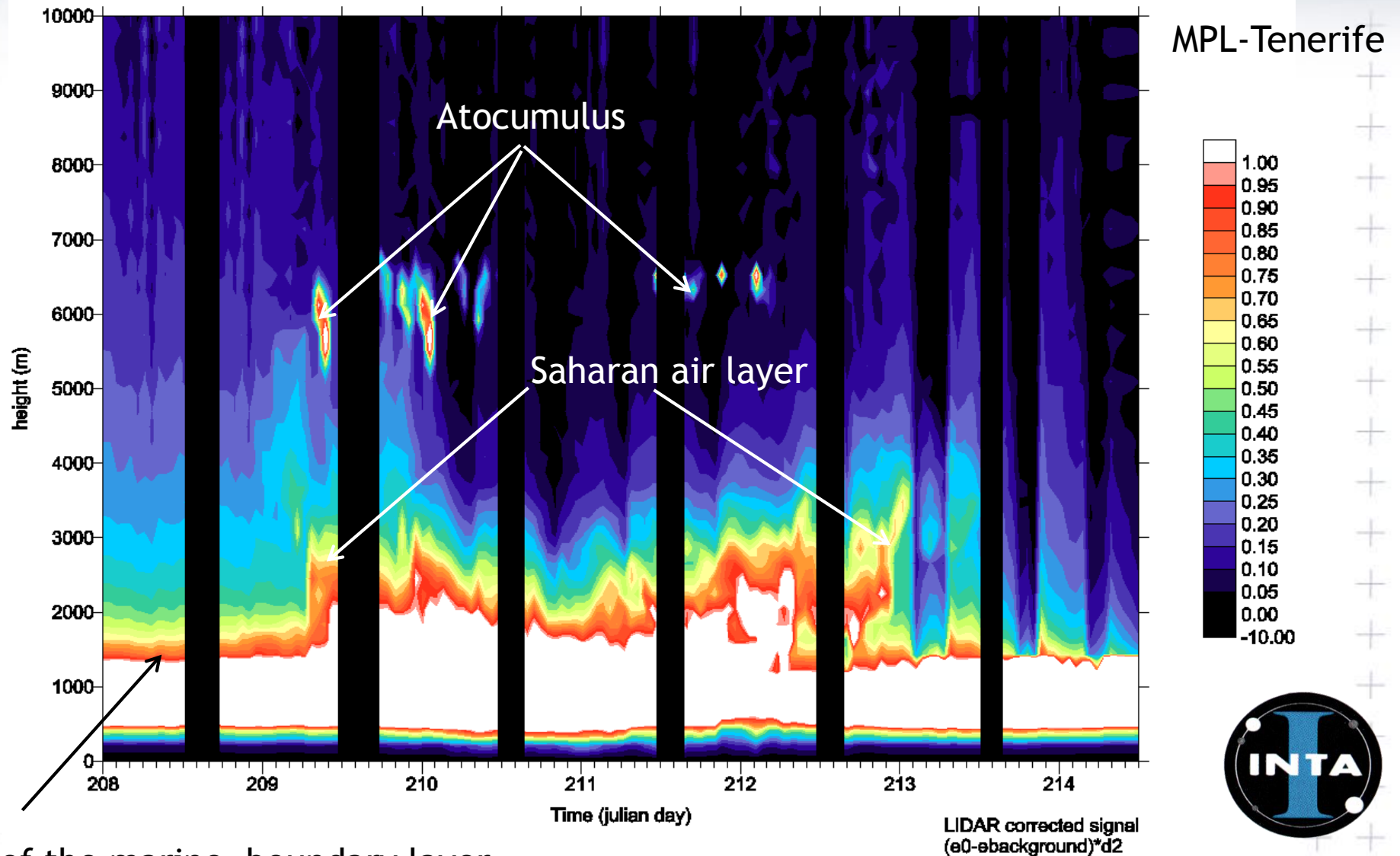


## GAW-GALION



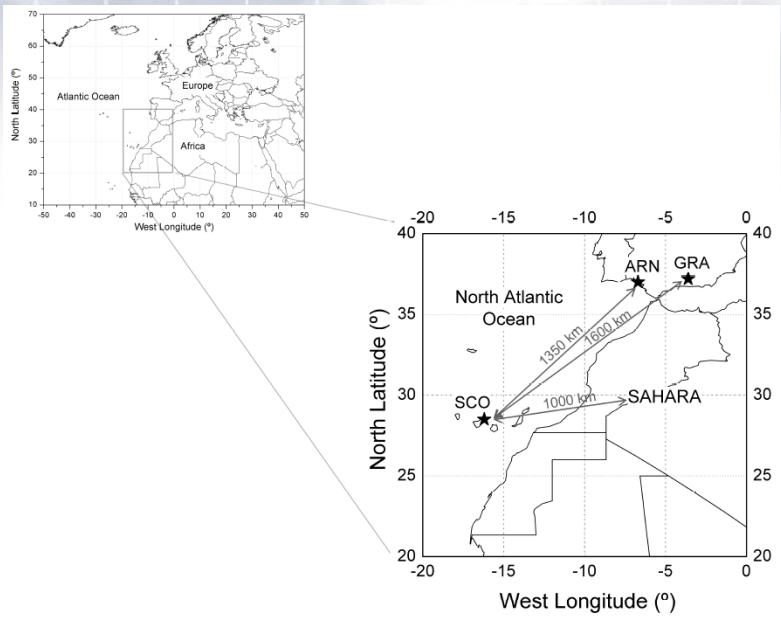
Distribution of stations as available through the cooperation between existing networks: **AD-NET** , **ALINE** , **CISLiNet** , **EARLINET** , **MPLNET** , NDACC , **REALM** .

## DUST EVENT 28 JULY - 2 AUGUST 2002



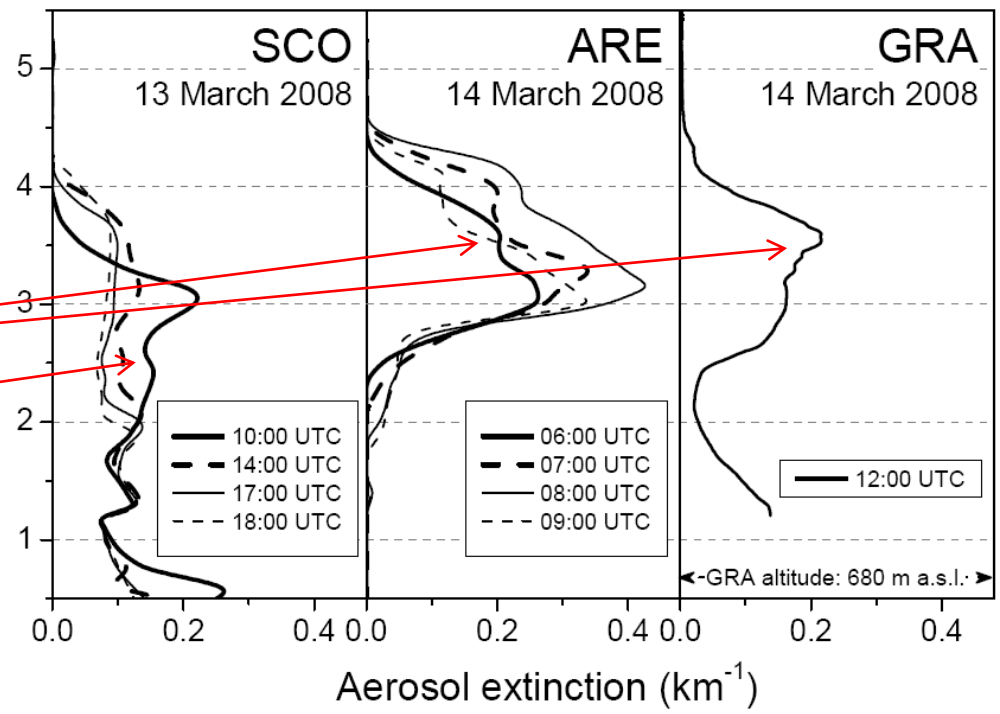
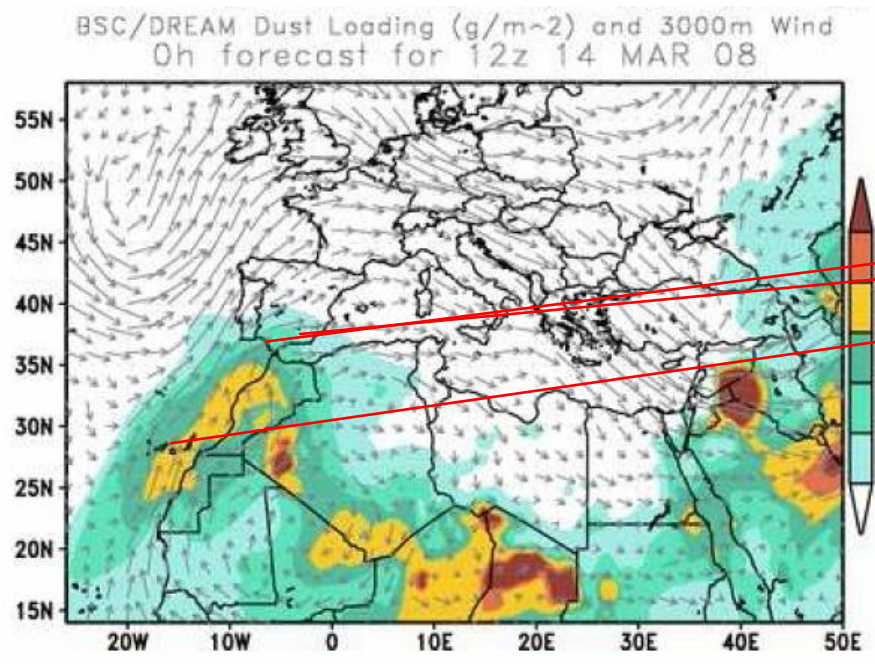
Top of the marine boundary layer



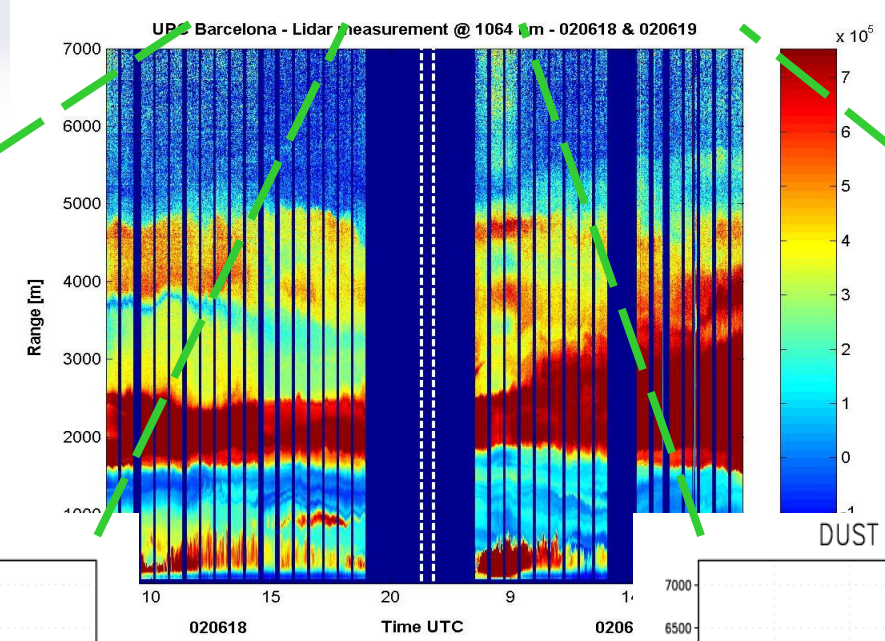


## A case study of dust transport from Canary Islands to Iberian Peninsula

Córdoba-Jabonero et al., ACP Discuss., 2010



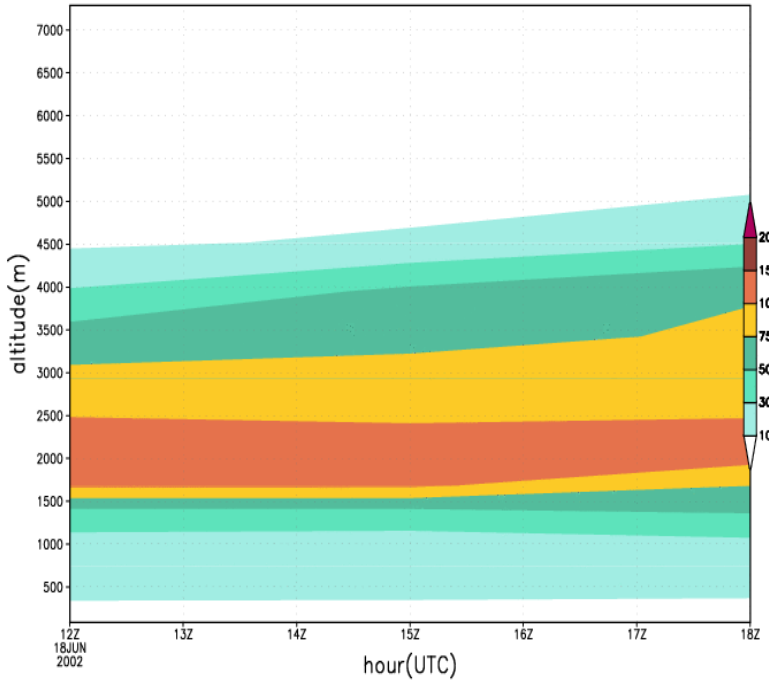
## Barcelona lidar vs DREAM BSC



EARLINET: Lidar-UPC,  
Barcelona

18-19 June 2002

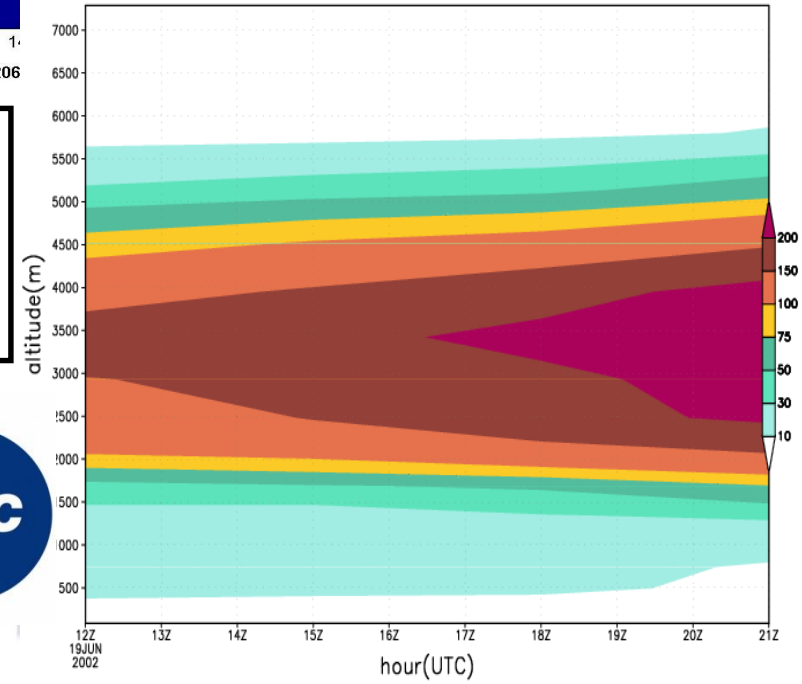
DUST CONC. ( $\mu\text{g}/\text{m}^3$ ) 18 JUN 2002



Vertical dust  
distribution  
validation:  
AIRLINET-DREAM



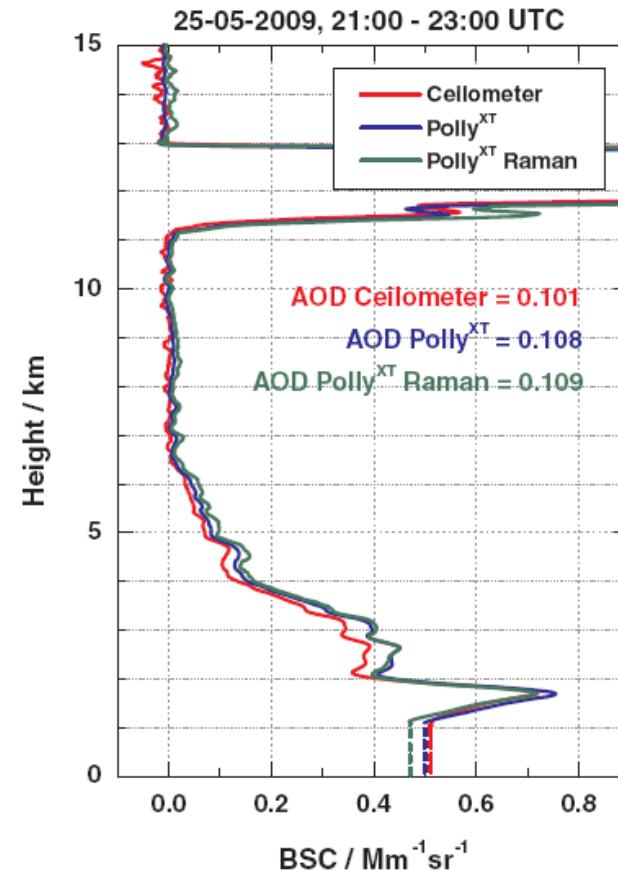
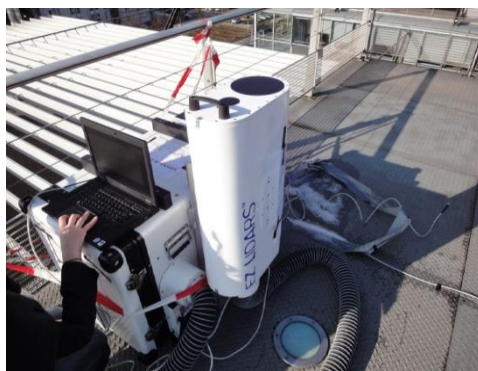
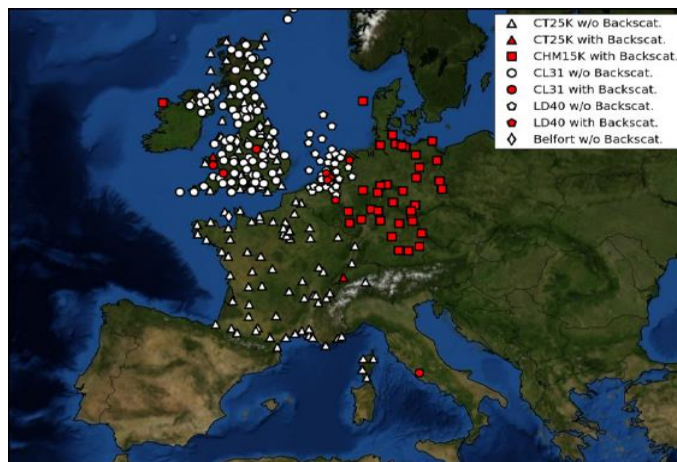
DUST CONC. ( $\mu\text{g}/\text{m}^3$ ) 19 JUN 2002





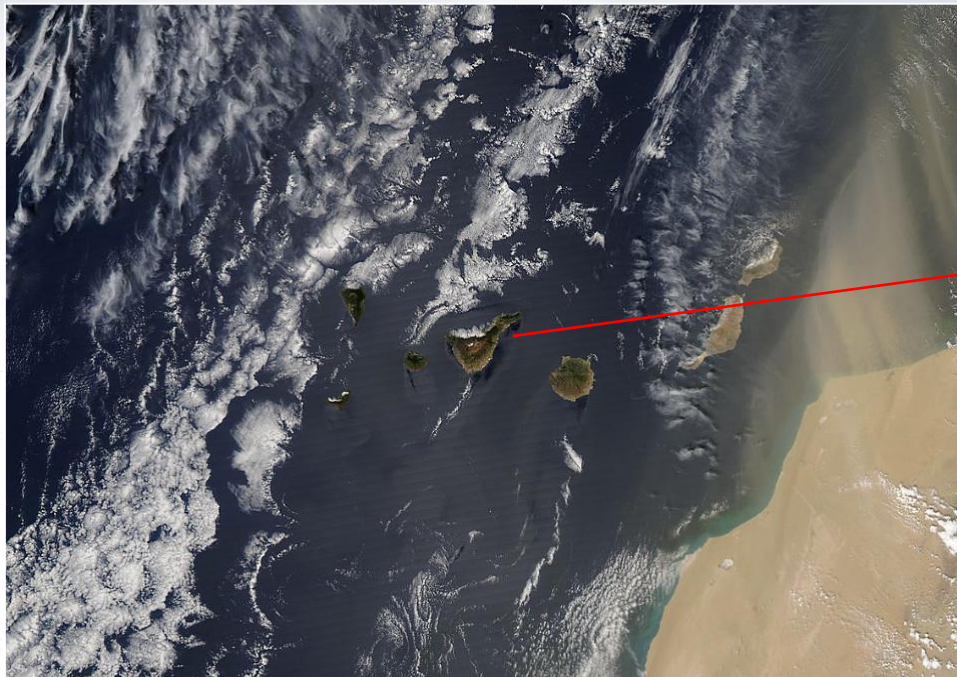
Met Services are replacing cloud-base ceilometer networks by aerosol backscatter profiling ceilometers (IR wavelength).

Objective: To monitor MLD (Mixing Layer Depth) based on several hundred profiling ceilometers (100km sampling)



Heese et al., Atmos. Mes. Tech. 2010,  
Ceilometer-lidar inter-comparison:  
backscatter coefficient retrieval and  
signal-to-noise ratio determination

**Optimal for desertic areas !!**



Viasala Ceilometer  
CL-51

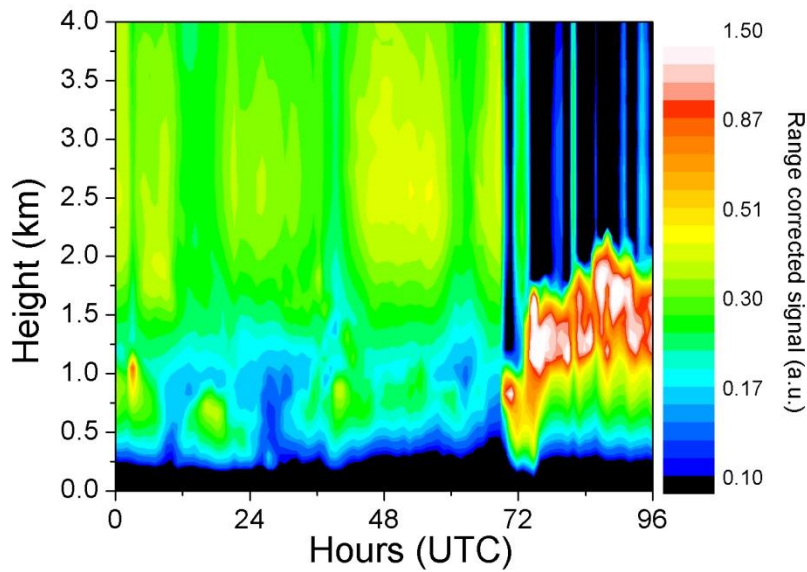
## MicroPulse Lidar and Ceilometer inter-comparison during Saharan dust intrusions over the Canary Islands

Y. Hernández, S. Alonso-Pérez, E. Cuevas, C. Camino, R. Ramos, J. de Bustos, C. Marrero, C. Córdoba-Jabonero and M. Gil (2011)

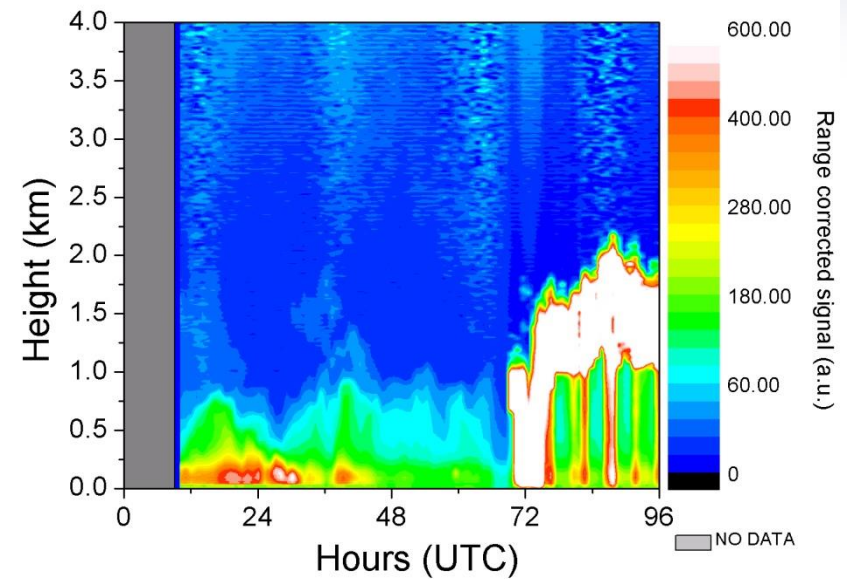
**Campaign performed from January to March 2011 in Tenerife island**



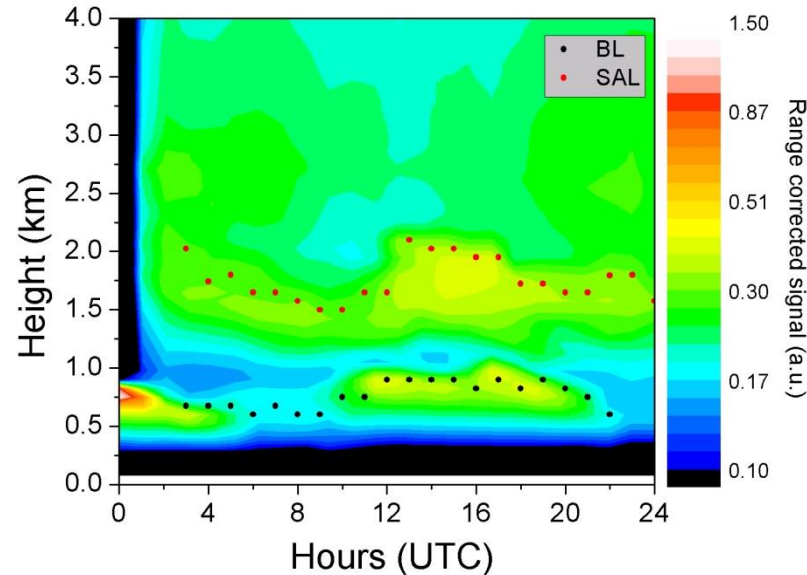
MPL-3 - Sta. Cruz de Tenerife. Mar 31- Apr 3, 2011



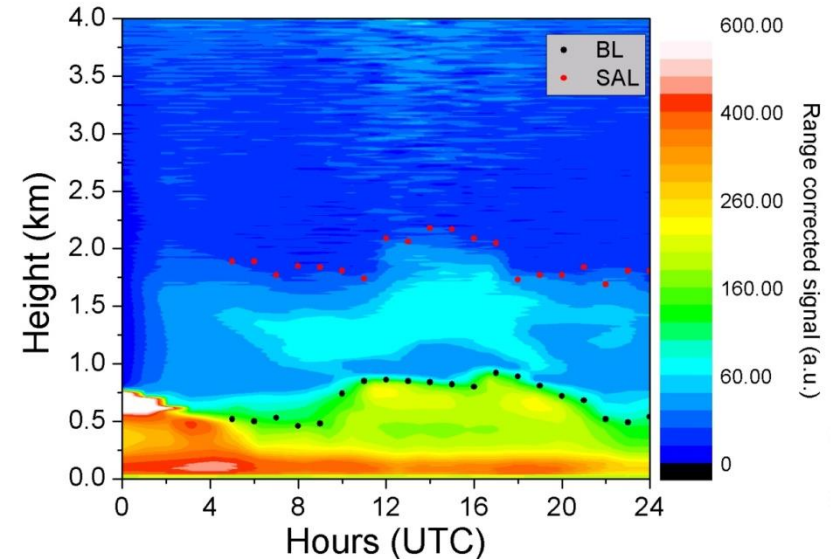
CL51 - Sta. Cruz de Tenerife. Mar 31- Apr 3, 2011



MPL-3 - Sta. Cruz de Tenerife. Feb 24, 2011

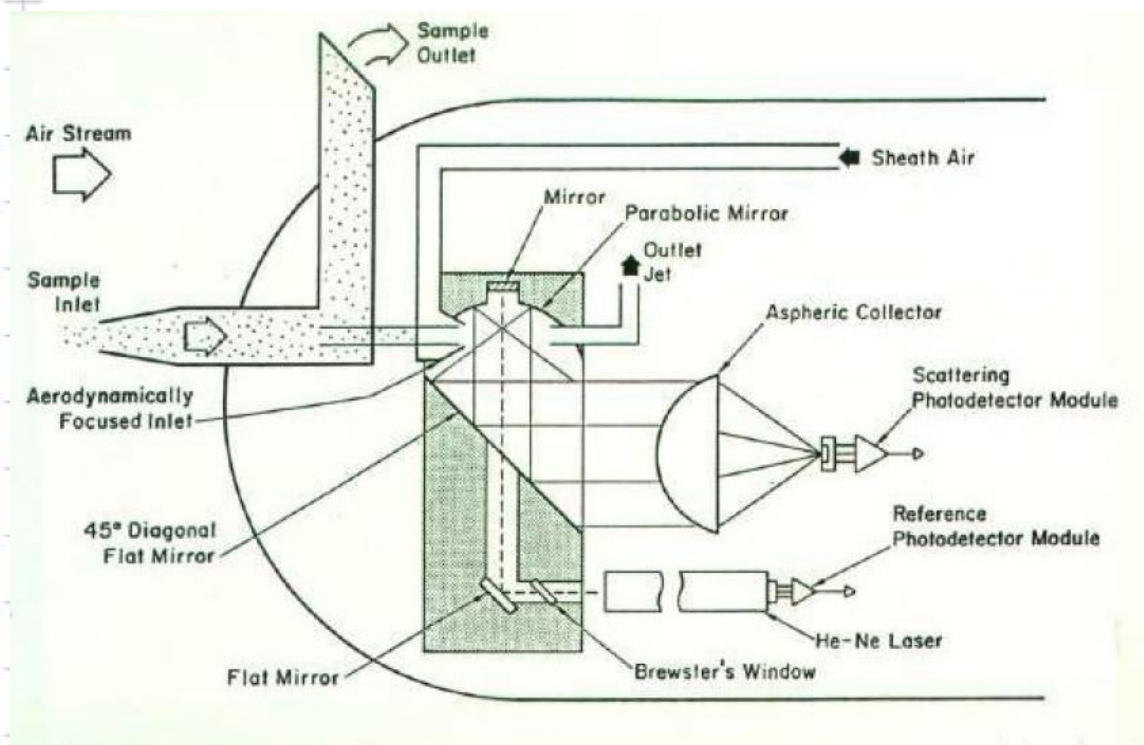


CL51 - Sta. Cruz de Tenerife. Feb 24, 2011





INTA C212-200 N/S 301



## PCASP-100X sonde

Optical counter

0.1 - 3.0  $\mu\text{m}$  en 15 channels

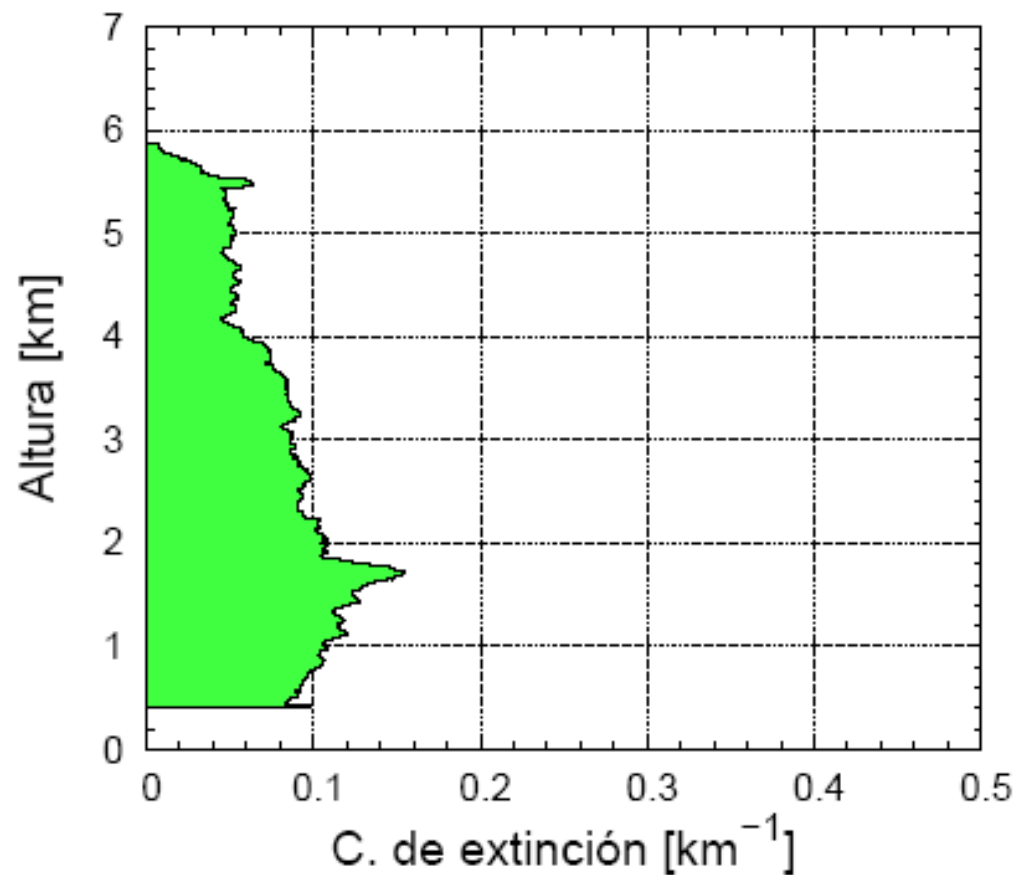
Up to 20,000 particles /s

A size distribution /s

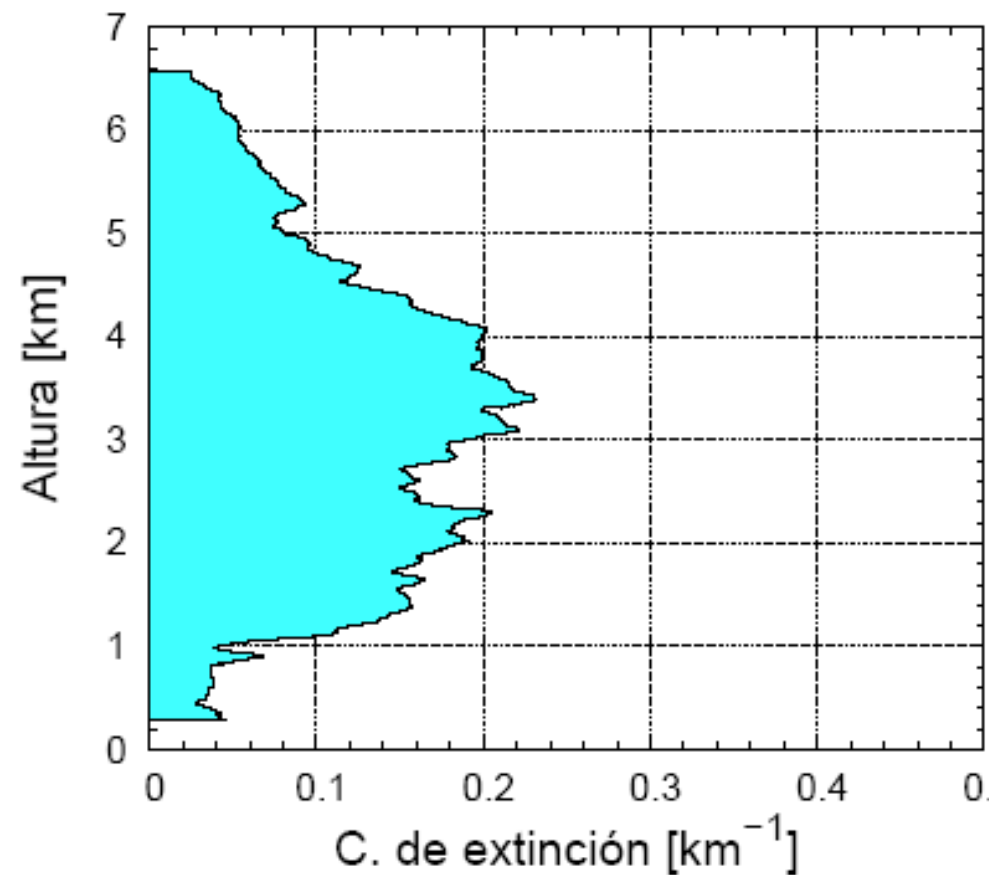




20 - julio - 05



22 - julio - 06



Andrey, 2011 (PhD)

# Index

- Aerosols and dust background
- In-situ dust characterization
- In-situ dust estimations (Visibility)
- Ground based remote sensing
- Summary

## In-situ measurements and surface remote sensing compared to satellite

### Advantages

### Disadvantages

In-situ  
measurements

Ground-based  
remote sensing

Satellite remote  
sensing

## In-situ measurements and surface remote sensing compared to satellite

### Advantages

#### In-situ measurements

- very straightforward;
- unique dust physical and chemical information;
- universal applicability (no sky conditions dependent)
- Time high resolution (minutes)

#### Ground-based remote sensing

- high information on dust (transmitted light dominates over reflected);
- non-intrusive measurements;
- easy access to equipment;
- column dust information

#### Satellite remote sensing

- global coverage; (global dust)
- non-intrusive measurements

### Disadvantages

- intrusive measurements;
- local coverage in some sites

- local coverage;
- indirect measurements;
- very limited capability in presence of clouds (Photom.)

- limited on information aerosol (No chemical composition, size distribution, low temporal resolution);
- no access to equipment



Ground-based dust observations are essential for:

- High-accuracy optical and chemical characterization of dust
- Dust model verification, validation and assimilation
- Dust satellite-based products validation

Ground based ‘supersites’ equipped with complete high-quality dust observation programs (in-situ and remote sensing) constitute unique platforms for satellite-based dust observations and dust models quality assurance

## In-situ observations & long term monitoring:

mass concentration:

bulk aerosol mass (TSP,  $PM_{10}$ ,  $PM_{2.5}$ )

bulk dust mass (total dust,  $dust_{10}$ ,  $dust_{2.5}$ ): 1 or more tracers methods

chemical composition

bulk aerosol = dust + pollutants ( $SO_4^{=}$ ,  $NO_3^-$ ,  $NH_4^+$ ) + sea-salt + trace metals + OC + EC

number size distribution

10nm - 500nm + 0.5 - 20  $\mu m$  (no distinction between dust and other aerosols)

optical properties

scattering and absorption coefficients

complementary measurements: mixing state, mineralogy, isotopic characterization, etc...

Close cooperation and data exchange between Met. Services, Air quality networks/Agencies, and Universities is highly recommended !!

## In-situ remote remote sensing:

Total column dust optical properties (sunphotometers):

Aerosol optical depth (AOD)

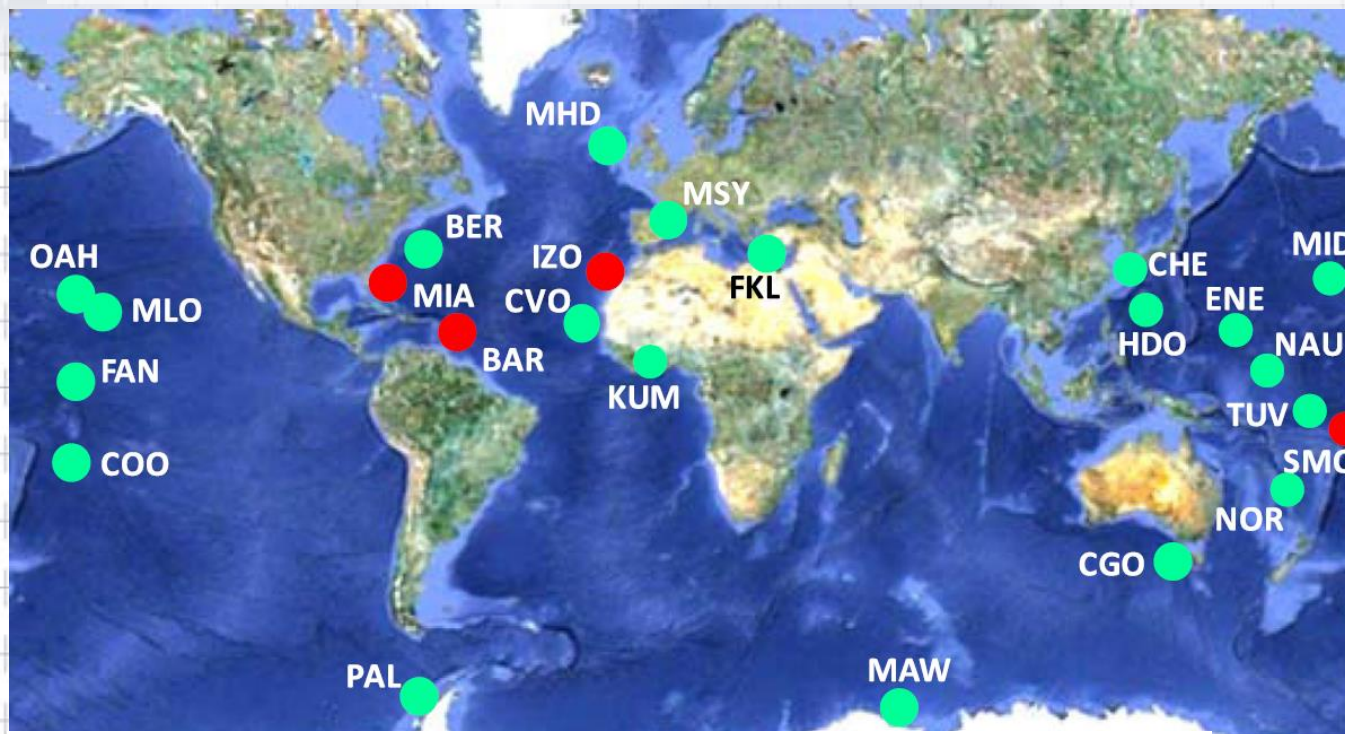
Angström Exponent



Dust vertical distribution

Corrected vertical backscattering

Extinction vertical distribution

## Long term monitoring dust background-observatories:



-  at least 4 years
-  Active during the last 20 years

Review Article

Aeolian Research Aeolian Research 6 (2012) 55–74

A review of methods for long term in situ characterization of aerosol dust

Sergio Rodríguez <sup>a,\*</sup>, Andrés Alastuey <sup>b</sup>, Xavier Querol <sup>b</sup>

**Synergies between air quality and dust monitoring should be found. This is of critical importance for big cities in Northern Africa and Middle East**

# 3<sup>rd</sup> Training Course on WMO SDS-WAS products (satellite and ground observation and modelling of atmospheric dust)

*Muscat-Oman, December 8-12, 2013*



## Ground observations of mineral dust

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